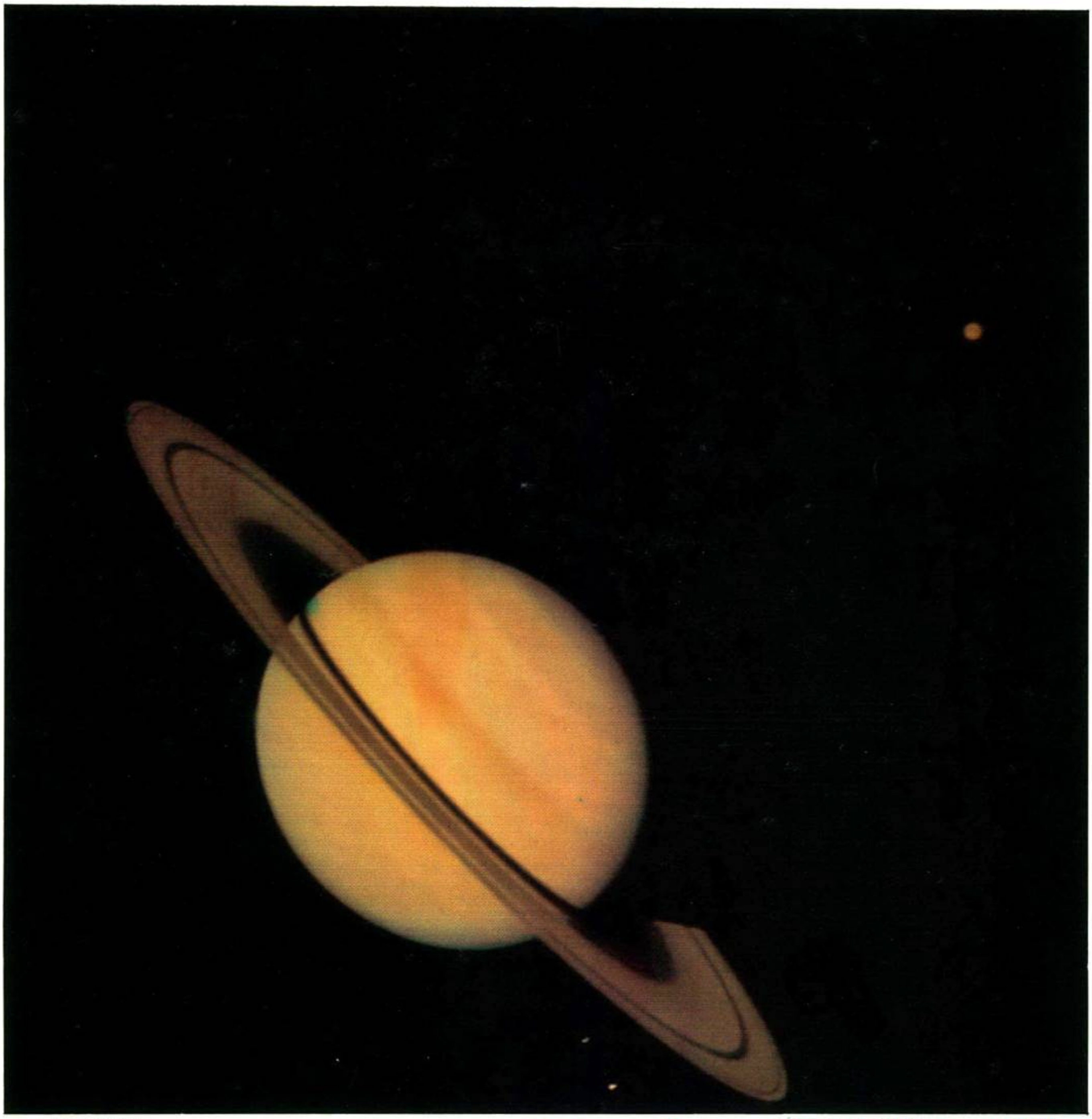
ASTRONOMY

December 1980
$2
UK 95p

Voyager Approaches Saturn
Closer to Creation
Keeping Warm While Stargazing



Saturn from 47 Million Miles

Meade System 2000

Think of the dimensions a truly research-quality instrument would add to your observing program.

Then consider moving up to the quality and performance of a Meade 4-inch or 8-inch Schmidt-Cassegrain. For Meade Schmidt-Cassegrains, both optically and mechanically, really are the finest instruments of their kind ever offered the serious observer and astrophotographer.

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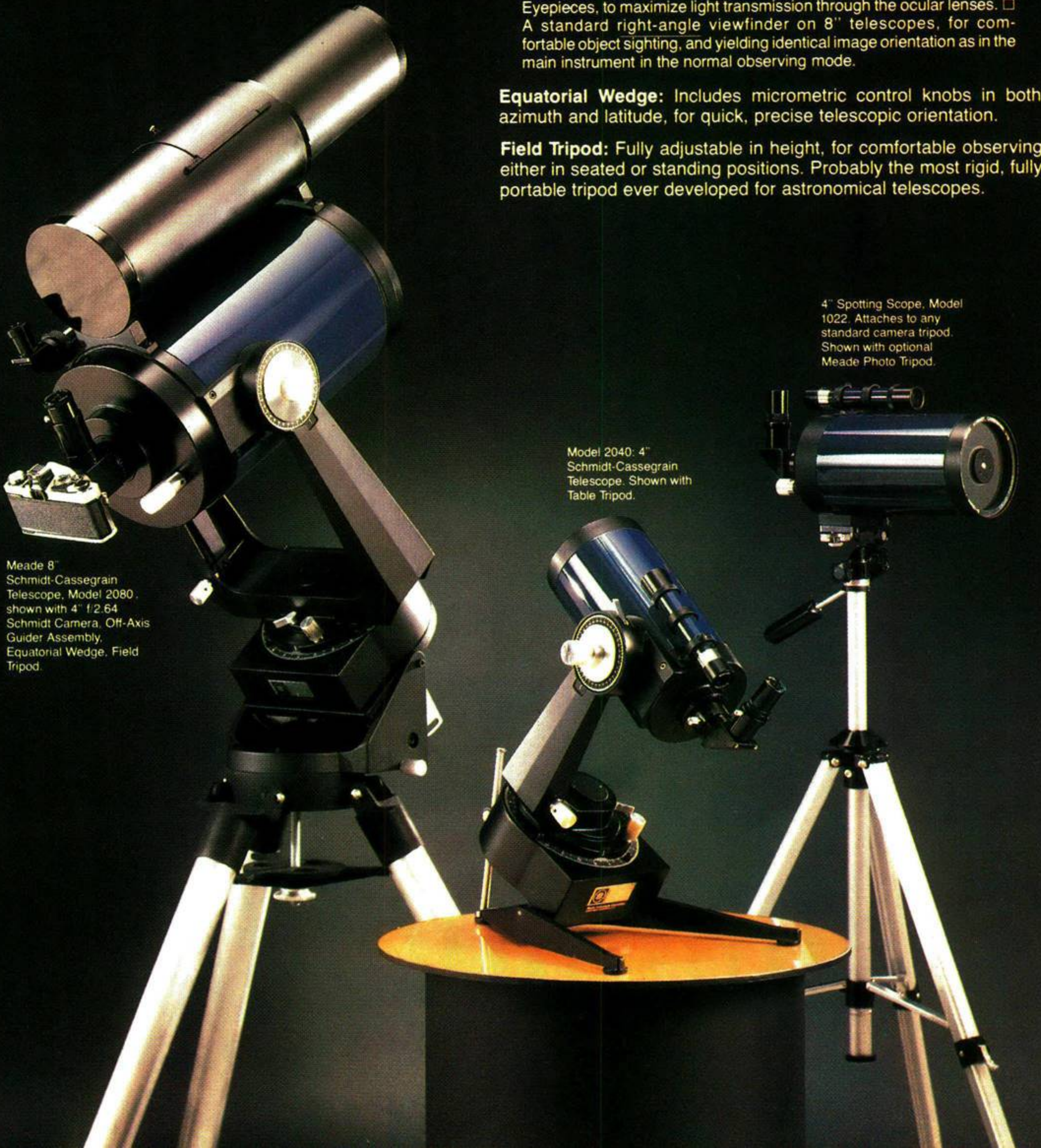


4" Spotting Scope, Model 1022. Attaches to any standard camera tripod. Shown with optional Meade Photo Tripod.

Model 2040: 4" Schmidt-Cassegrain Telescope. Shown with Table Tripod.

Meade 8" Schmidt-Cassegrain Telescope, Model 2080, shown with 4" f/2.64 Schmidt Camera, Off-Axis Guider Assembly, Equatorial Wedge, Field Tripod.

Schmidt-Cassegrains

The System: Perhaps most importantly of all, Meade System 2000 Schmidt-Cassegrains are part of a wide and versatile system: the amazing 4" f/2.64 Schmidt Camera; 4" Schmidt-Cassegrain Photo-Guide Telescope with Illuminated Reticle Eyepiece; Dual-Axis Drive Corrector, and more — all of which attach easily and directly to 8" models.

Aesthetic Design: In the beauty of their enameled deep-blue tube surfaces, in the fineness of their machine-tooled mechanical components, Meade System 2000 models are light years ahead of the competition. See the System 2000 for yourself, and no further explanation will be necessary.

Warranty: As with all Meade products, the System 2000 is fully covered by the Meade One-Year Limited Warranty. See the Meade catalog for full details on this no-risk protection of your investment.

PRICE LIST

Model 2040:	
4" Schmidt-Cassegrain Telescope with Fork Mount ...... Base Price	**$545**
Model 2080:	
8" Schmidt-Cassegrain Telescope with Fork Mount ...... Base Price	**785**
Equatorial Wedge 4"/8"	**50**
Field Tripod 4"/8"	**140**
Table Tripod 4"	**35**
Table Tripod 8"	**45**
Model 1020: 1000mm f/10 Telephoto Lens	**325**
Model 1022: 4" Spotting Scope	**395**
Meade Photo Tripod for Models 1020 or 1022	**50**
Model 2066: 4" f/2.64 Schmidt Camera	**435**

All prices include packing. Complete telescopes are packed in luggage-quality foam-lined carrying cases. All prices F.O.B. Costa Mesa, California. Calif. residents add 6% sales tax.

Catalog: Send $3.00 (Outside North America $5.00 for air mail) for your copy of the new 48-page Meade Color Catalog **No. 80-C**, with full details on Meade Schmidt-Cassegrains, Newtonian reflectors, refractors, accessories.

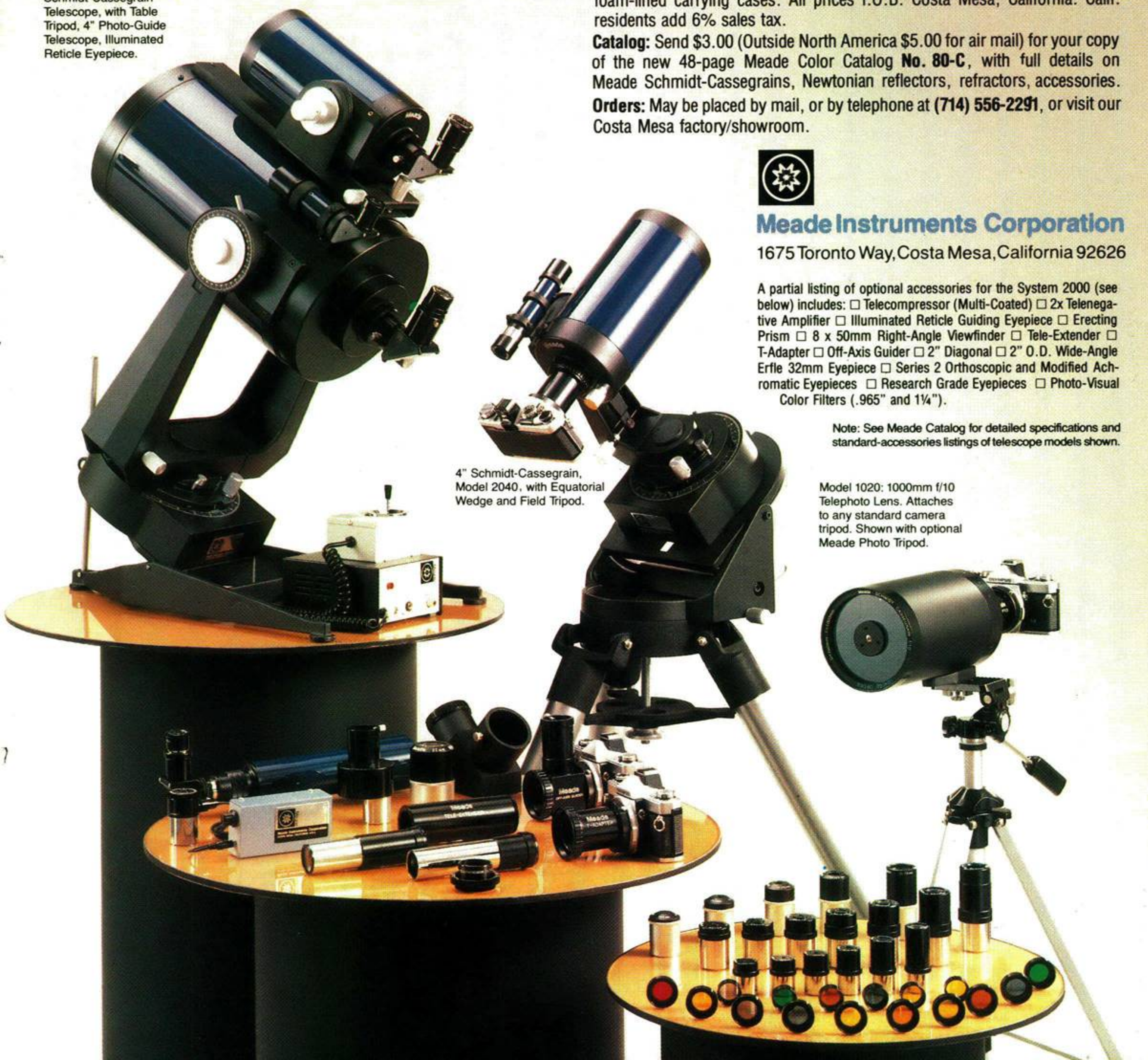
Orders: May be placed by mail, or by telephone at **(714) 556-2291**, or visit our Costa Mesa factory/showroom.

Meade Instruments Corporation

1675 Toronto Way, Costa Mesa, California 92626

A partial listing of optional accessories for the System 2000 (see below) includes: ☐ Telecompressor (Multi-Coated) ☐ 2x Telenegative Amplifier ☐ Illuminated Reticle Guiding Eyepiece ☐ Erecting Prism ☐ 8 x 50mm Right-Angle Viewfinder ☐ Tele-Extender ☐ T-Adapter ☐ Off-Axis Guider ☐ 2" Diagonal ☐ 2" O.D. Wide-Angle Erfle 32mm Eyepiece ☐ Series 2 Orthoscopic and Modified Achromatic Eyepieces ☐ Research Grade Eyepieces ☐ Photo-Visual Color Filters (.965" and 1¼").

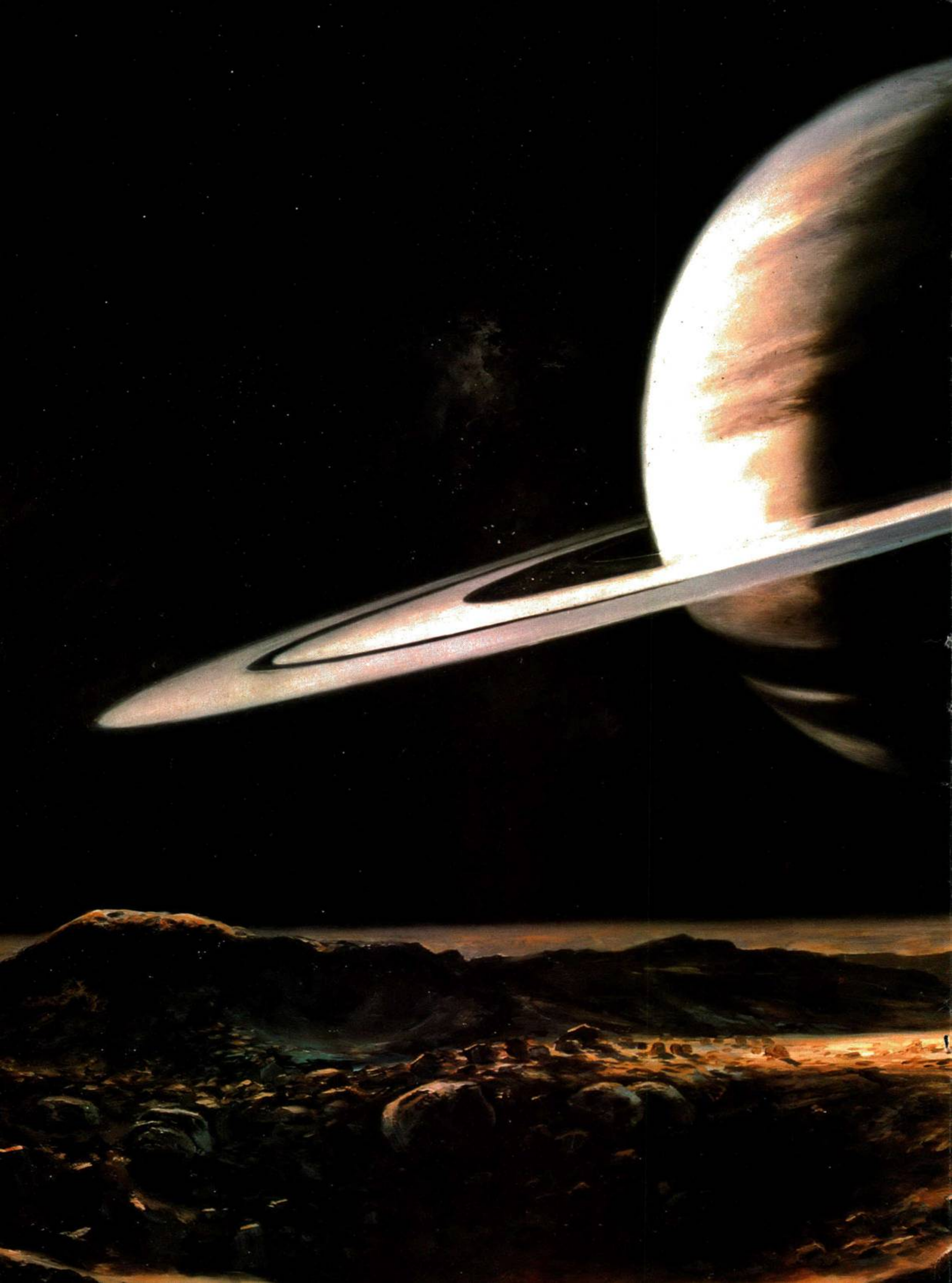
Note: See Meade Catalog for detailed specifications and standard-accessories listings of telescope models shown.

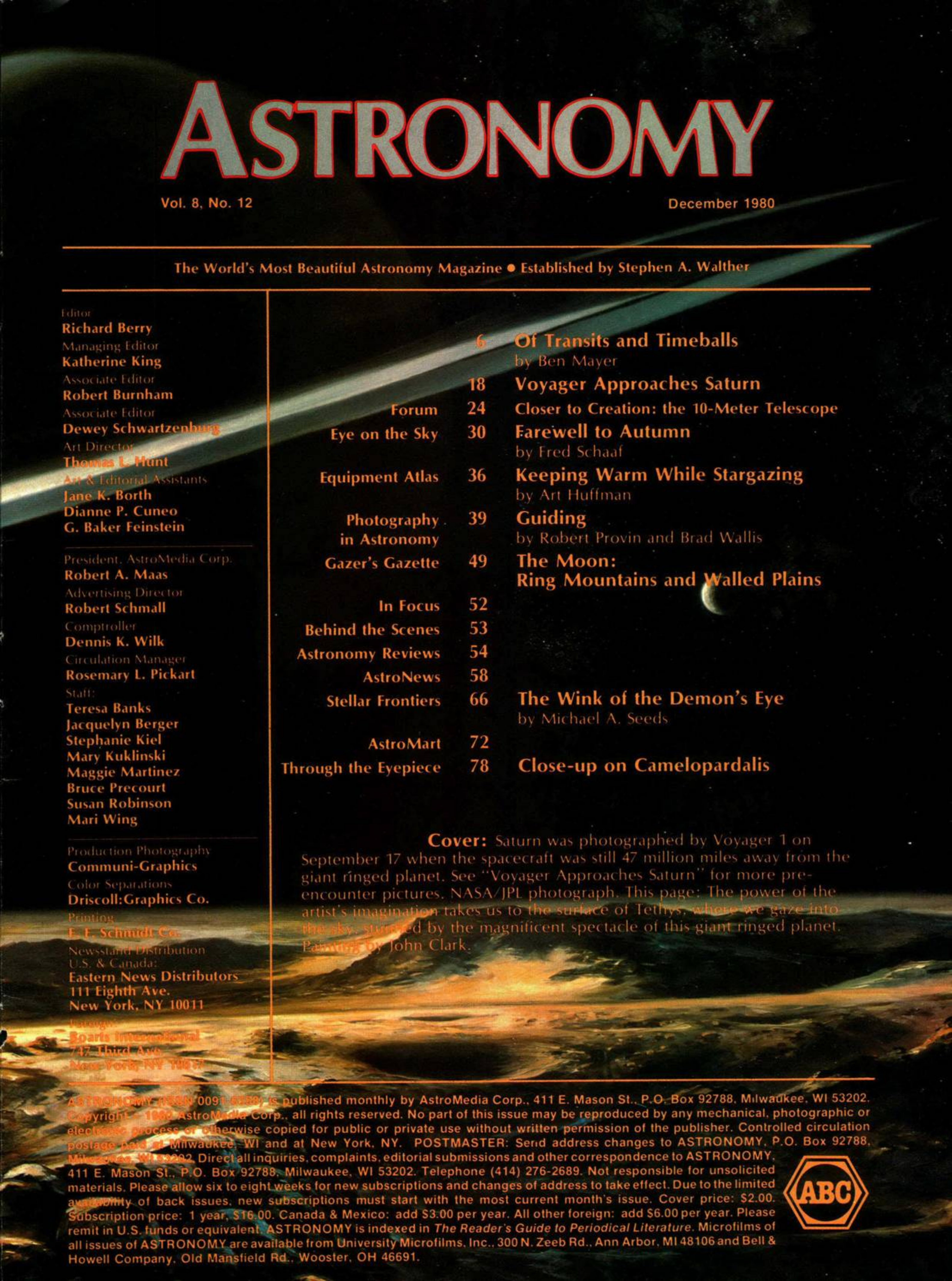


Model 2080: 8" Schmidt-Cassegrain Telescope, with Table Tripod, 4" Photo-Guide Telescope, Illuminated Reticle Eyepiece.

4" Schmidt-Cassegrain, Model 2040, with Equatorial Wedge and Field Tripod.

Model 1020: 1000mm f/10 Telephoto Lens. Attaches to any standard camera tripod. Shown with optional Meade Photo Tripod.





ASTRONOMY

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Cover: Saturn was photographed by Voyager 1 on September 17 when the spacecraft was still 47 million miles away from the giant ringed planet. See "Voyager Approaches Saturn" for more pre-encounter pictures. NASA/JPL photograph. This page: The power of the artist's imagination takes us to the surface of Tethys, where we gaze into the sky, stunned by the magnificent spectacle of this giant ringed planet. Painting by John Clark.

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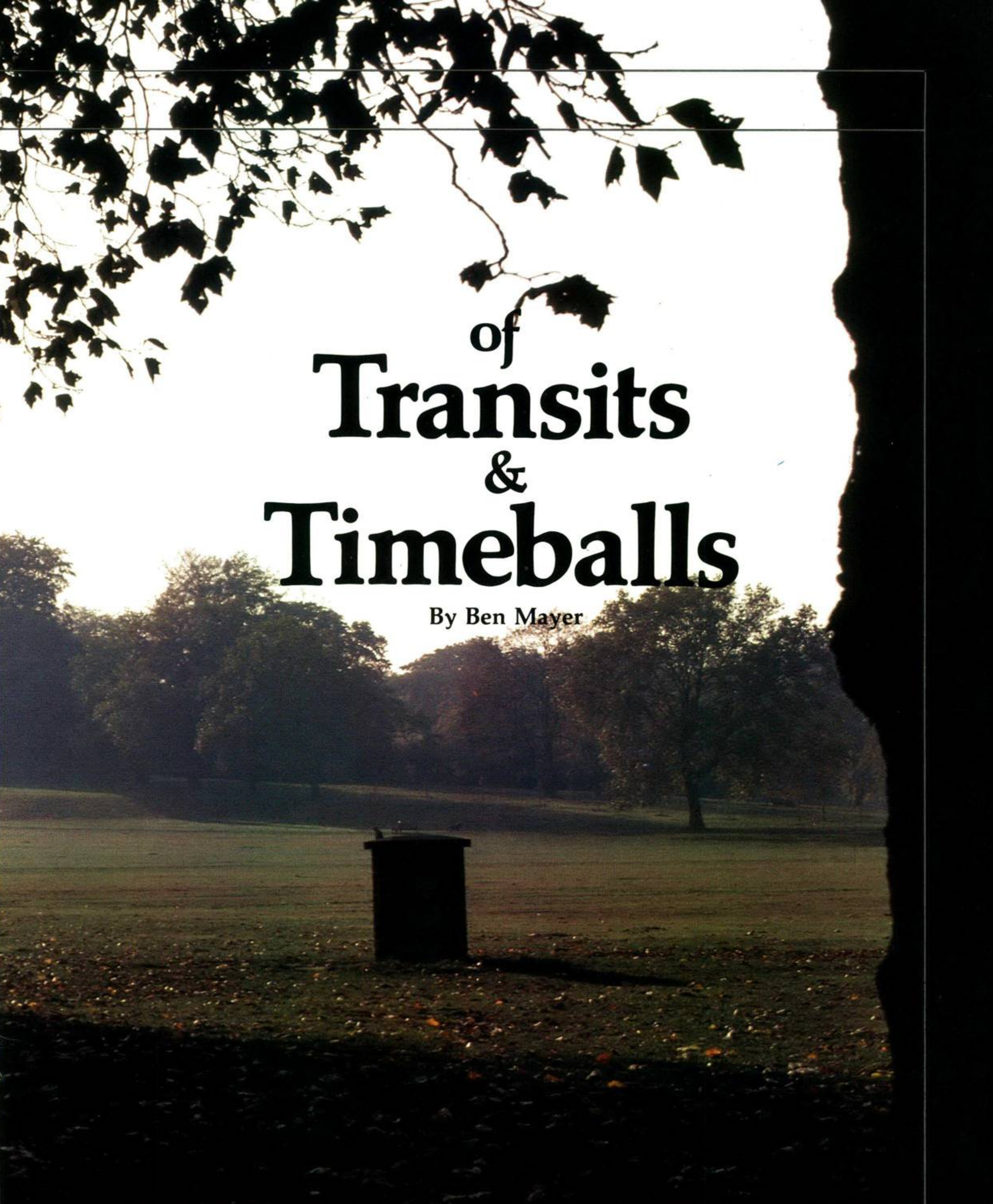
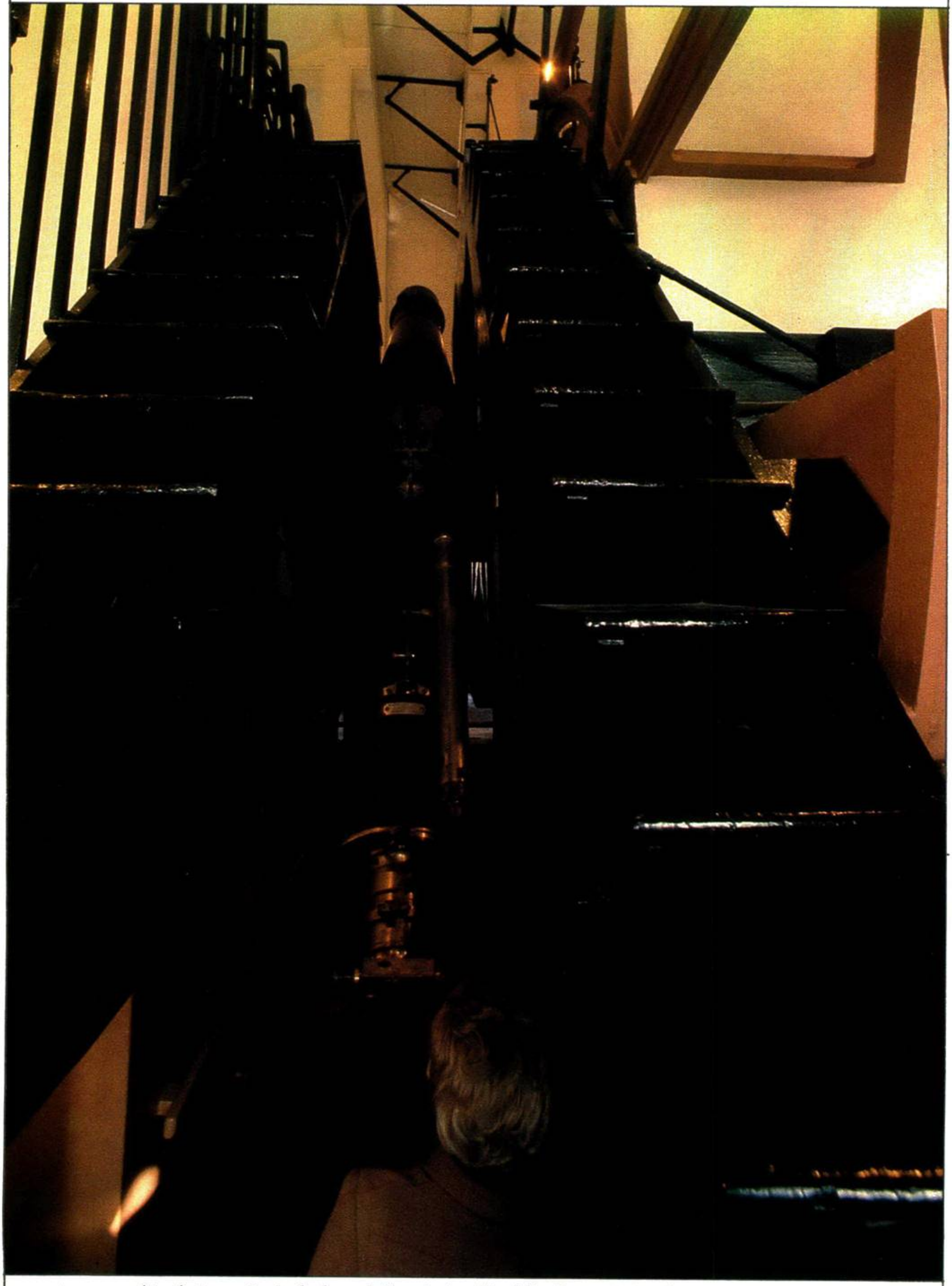
# of Transits & Timeballs

By Ben Mayer



The Royal Greenwich Observatory as seen from North Greenwich Park.



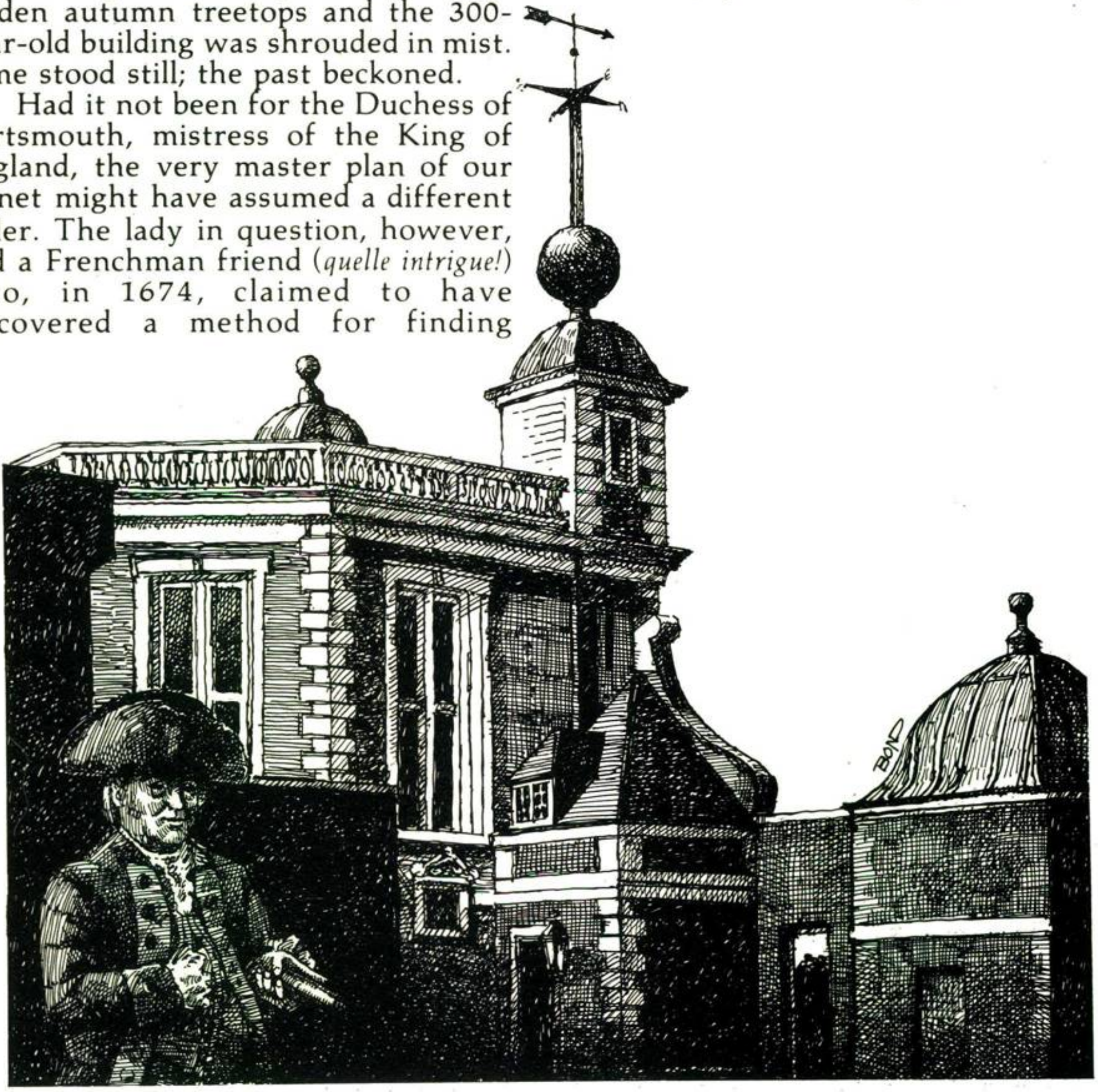
Airy's transit circle has defined the World's Prime Meridian since 1884.

Time lies enshrined at the Royal Observatory in Greenwich, England. It inhabits the banks of the river Thames in London, where Shakespeare once rhapsodized "...Time, that old common arbiter...." Two thousand years earlier, the philosopher Pythagoras had hailed time as "the soul of the world."

Neither bard nor Greek mathematician would have been able to identify with the jet-lagged traveler whose digital watch was yet displaying yesterday's California midnight even as he set foot in the morning dew of London's Greenwich Park. The symmetrical turreted outline of the old observatory rose majestically above golden autumn treetops and the 300-year-old building was shrouded in mist. Time stood still; the past beckoned.

Had it not been for the Duchess of Portsmouth, mistress of the King of England, the very master plan of our planet might have assumed a different order. The lady in question, however, had a Frenchman friend (*quelle intrigue!*) who, in 1674, claimed to have discovered a method for finding longitude at sea by observing the positions of the Moon against a background of stars. Theoretically his claim was valid, but in practice the scheme was unworkable because neither the motion of the Moon nor the positions of the stars were yet known to sufficient accuracy. "When King Charles II was informed of these facts," chronicled John Flamsteed (1648-1719), the first Astronomer Royal, "he ordered that the work must be carried out in Royal fashion." Neither ship owners nor sailors were to be deprived of any help that the heavens could supply, whereby navigation could be made safer.

Therefore his most serene Majesty was pleased to decree that an observatory should be built "within our



The Time-ball installed in 1833 still drops at 1 p.m. every day.

Park at Greenwich, upon the highest Ground, at or near the Place where the Castle stood, with lodging Rooms for our astronomical Observator and Assistant...."

Thus the Royal Observatory was founded in 1675. The architect was none other than Sir Christopher Wren, master re-builder of London's churches after the great fire, designer of St. Paul's Cathedral, and himself a distinguished astronomer. The purpose of the establishment was specifically stated: "In order to the Finding out of the Longitude of Places for perfecting Navigation and Astronomy."

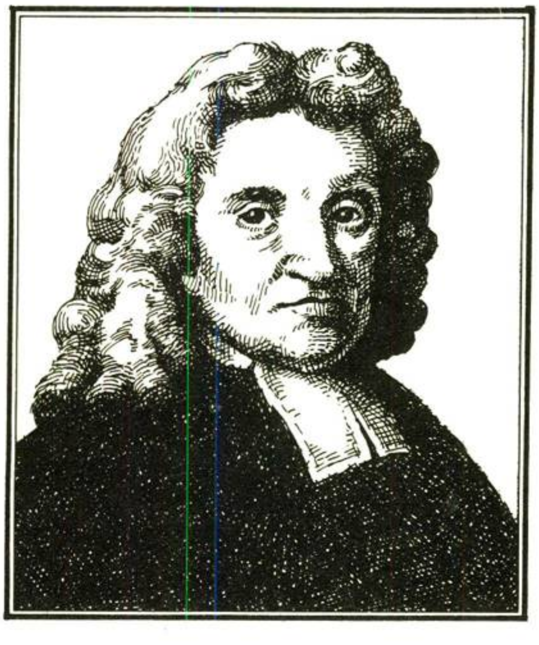
The building, named Flamsteed House after the chief astronomer, was constructed "for the Observator's Habitation and a little for Pompe." To save money, the foundations of the old castle were eventually used and the construction costs of £500 were raised through the sale of decayed gunpowder.

The main architectural feature of the structure was the "Great Room" designed specifically for astronomical use. Its shape was to establish it as the "octagon room," which today appears much as it did when first designed by the talented Wren. Most of the paneling and the ceiling are original, and the telescopes and quadrants on display are similar to those used in the room between 1676 and 1830. After 1830, this space became a board room, then a library, a store, a museum, and once a year on visitation day, a banquet room. The clocks with their 13-foot pendulums behind the wainscot remained. They had first been used by Flamsteed to check the Earth's rotation. A contemporary etching shows the octagonal room as it was when Flamsteed rested a long refractor on a ladder-like support to peer at the stars from the eastern window. Upon entering the room today (after climbing the narrow staircase in the south tower), it is as if one had taken leave of the twentieth century and entered into the seventeenth.

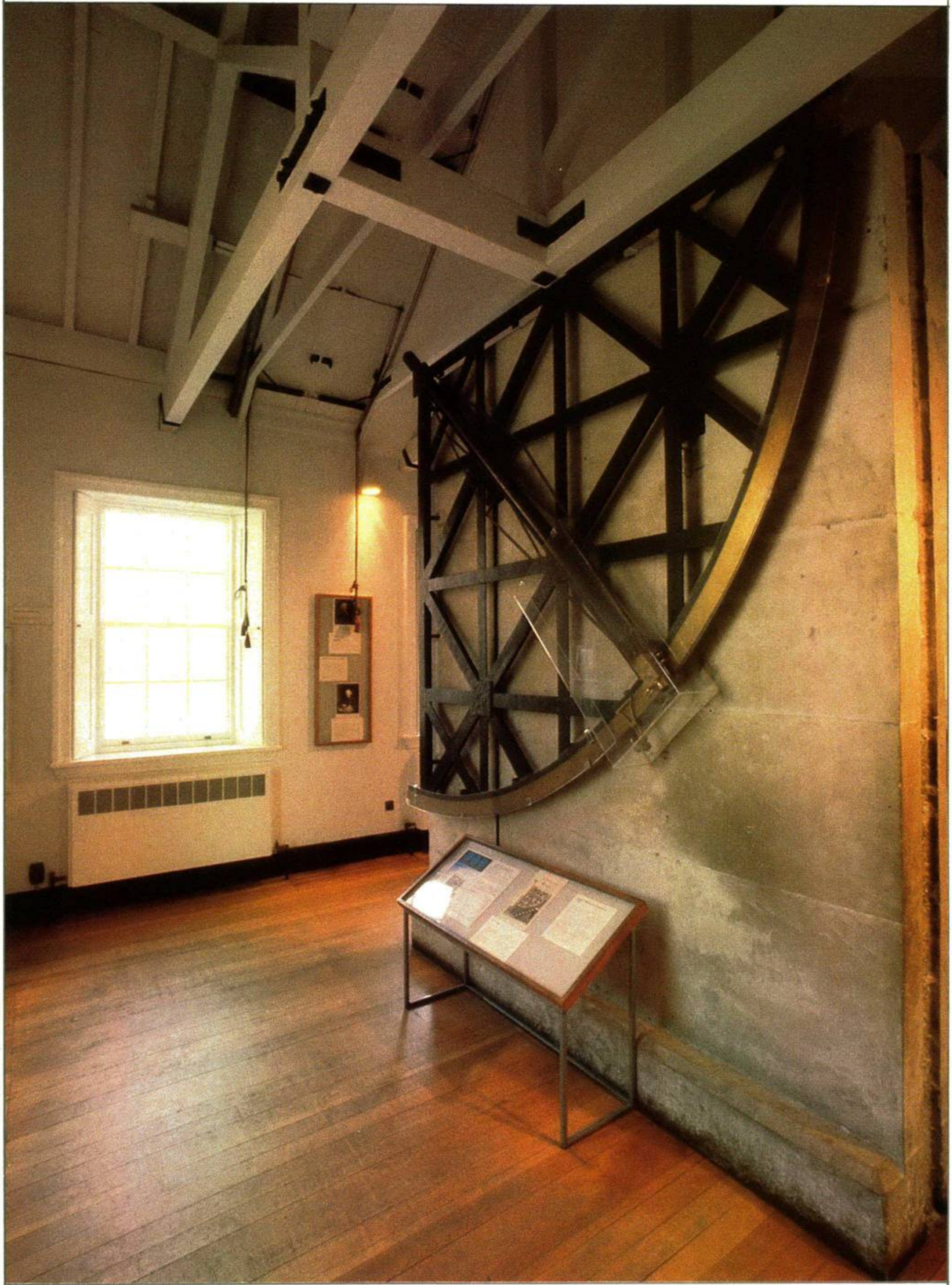
The splendor of a nation ascending toward world dominance through naval power combined with maritime commerce becomes evident through the countless displays which have been thoughtfully assembled. It seems, suddenly, as if the modern vessels moored in the bend of the River Thames some distance below are galleons, ready to set out for distant shores in lands yet unexplored.

Yet one overriding problem had always beset the masters of these sailing ships and men-o'-war as they cast off from the shelter of their London docks: their positions at sea were not known. Even though latitude could be easily determined anywhere on Earth (through the well-known and predictable elevations of the Sun at any time of the day or year), their location in the other coordinate, the vital longitude, remained a matter of conjecture based on inaccurate dead reckoning.

Flamsteed himself set the pace by measuring and recording the position of nearly 3000 stars (to an accuracy of about 10 seconds of arc) during his tenure from 1675 to 1719. The work was continued by Edmond Halley, of comet fame, from 1720 to 1742, and then by the third Astronomer Royal, James Bradley, who served from 1742 to 1762. Not only did Bradley discover nutation (the Moon's influence on the precession of the Earth), but his observations assumed such a degree of



John Flamsteed was the first of the Astronomers Royal.



8-foot mural quadrant by John Bird hangs from Halley's stone meridian wall.

Octagon Room — today and as it was in 1676.

The Greenwich Meridian is inlaid in the Courtyard of the Royal Greenwich Observatory.

importance that a second building was constructed just south of Flamsteed House and Halley's original quadrant wall and instrument were installed in it. Bradley's own transit was also housed in this structure, and from 1750 to 1850 the Greenwich Meridian passed through the center of this instrument. Britain's first Ordnance Survey maps were based on Bradley's meridian.

Accurate timekeeping became increasingly important to establish longitude at sea and was critical in the practical application of astronomy. To determine longitudes, the precise time must be determined at some standard longitude, or meridian, of the Earth, such as Bradley's running through Greenwich. Anyone having an exact timepiece could then ascertain his own longitude, as easily as he could find his latitude. Even for ships far across the seas, being able to synchronize the moment of midday with the exact time of day or night then at Greenwich, could enable them to calculate longitude by determining the difference in time between themselves and Greenwich. Each hour of difference would constitute 15 degrees of longitude away from Greenwich since the entire globe measures 360 degrees or 24 hours in circumference.

In 1776 Nevil Maskelyne, fifth Astronomer Royal (1765-1811), published the first copy of the *Nautical Almanac and Astronomical Ephemeris* by the order of the "Commissioners of Longitude," and all that was needed now was an accurate method to keep time at sea over long periods. The delicate pendulum clocks of the day were accurate enough, but were useless on wave-tossed ships. A prize of £20,000 for a precise method of determining time at sea, was offered by the British government as an incentive and to reward inventors. Two solutions were soon put forth, one proposing the use of accurate tables of future lunar motions which might permit the use of the Moon as an astronomical clock. The other, and the one chosen, however, involved a mechanical clock invented by the Yorkshireman John Harrison. The most famous of these horological marvels are on display in the nearby Maritime Museum, notably the H-4 (Harrison's fourth chronometer) for which the prize was won. A copy of it was used by Captain Cook on his voyages between 1772 and 1780, and also on Captain Bligh's ill-fated *Bounty*. Contemporary records attest to the accuracy of these chronometers: It is reported that the H-4 lost only 15 seconds on a five-month passage from England to Jamaica.

As if to underscore the importance of applied astronomy to the field of navigation, control of the Royal Observatory passed to the Admiralty in 1818, while the Observatory, in turn, took charge of all the chronometers of the Navy in 1821, subsequently setting up a separate Nautical Almanac office. In 1833 the "time ball" was erected atop Flamsteed House. The Greenwich time ball was the world's first visual time signal and an important navigational aid before radio time signals. Upon its installation, the following notice was issued to all mariners:

> **"The Lords Commissioners of the Admiralty hereby give notice that a ball will hence forward be dropped, every day, from the top of a pole on the eastern turret of the Royal Observatory at Greenwich, at the moment of one-o'-clock p.m. solar time. By observing the first instant of its downward movement, all vessels in the adjacent reaches of the river as well as in most of the docks will thereby have an opportunity of regulating and rating their chronometers. The ball will be hoisted halfway up the pole at five minutes before one-o'-clock, as a preparatory signal, and close up at two minutes before one."**

Britannia may not rule the waves any more, but the red ball still drops precisely at one p.m. every day, just as it did when it was installed under the auspices of John Pond, the sixth Astronomer Royal (1811-35).

Every visitor to Greenwich will, whether surreptitiously or deliberately, straddle the one-inch-thick strip of brass inlaid between two straight courses of stone flanked by the cobblestones of the observatory courtyard. This is the Zero Meridian, perhaps the most famous aspect of the historical landmark. Even though the Meridian extends from the north pole to the south pole, and one could stand astride it in many other latitudes and climates, it is here and only here that the inevitable photographs are taken showing the visitor posing with one leg in the eastern and the other in the western hemisphere. Yet this is not Bradley's meridian, the original demarcation line established in 1750, but the second, undoubtedly final, zero meridian by which future mariners yet unborn will chart their departures and returns in combination with that second imaginary (and possibly more arbitrary) line which runs not through a city but cuts through the first point of Aries.

"PRIME MERIDIAN
OF THE WORLD"

says the sign:

"LATITUDE 51°21′38″
LONGITUDE 0°0′0″."

Bradley had one century of glory; in 1851 the meridian was moved 19 feet eastward during the term of the seventh Astronomer Royal, George Airy (1835-81). From then on, Airy's Transit Circle replaced all former instruments for fundamental meridian observations.

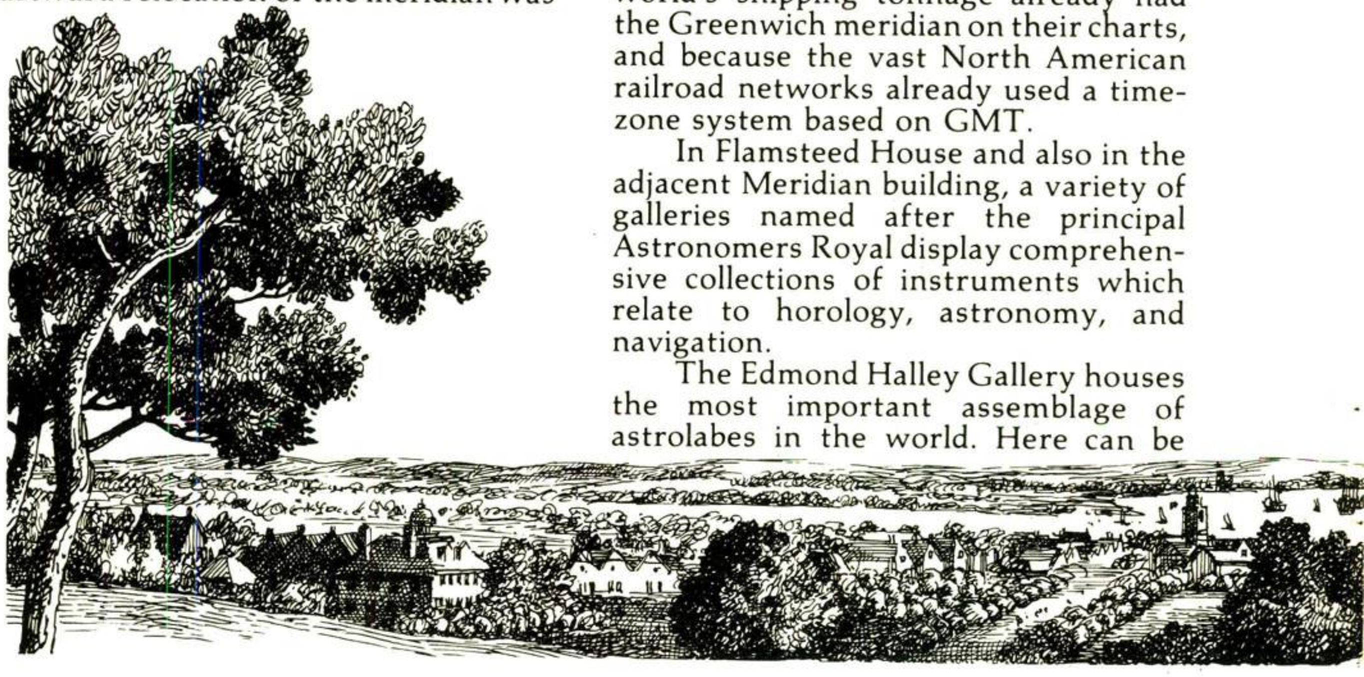
In terms of the accuracy of measurements at that time, the eastward relocation of the meridian was of no importance or concern. The 19 feet translated into an equivalent of one-fiftieth of a second of time, an entity then too small to be measured. One can only speculate how such a seemingly insignificant span, a mere six human strides, would compound today for a spacecraft circumnavigating the Earth months on end.

During Airy's tenure, Shepherd's electric motor clock was installed outside the gate of the observatory. With a 24-hour dial, it keeps universal time. One of the earliest clocks of its kind, it once controlled, by telegraph, synchronous dials and a time ball in London. From there, Greenwich Mean Time (GMT) was flashed by telegraph over the railway system. This was the start of "Railway Time," a standard which the British carried to the corners of their Empire.

Not until 1884 was the Greenwich meridian chosen as the Zero Longitude of the world and the basis of the international time zone system. Even though any meridian could have been adopted, an international conference convened in Washington, D.C. selected the one "passing through the centre of the transit instrument at Greenwich." The principal reasons for this choice were that at that time 72 percent of the world's shipping tonnage already had the Greenwich meridian on their charts, and because the vast North American railroad networks already used a time-zone system based on GMT.

In Flamsteed House and also in the adjacent Meridian building, a variety of galleries named after the principal Astronomers Royal display comprehensive collections of instruments which relate to horology, astronomy, and navigation.

The Edmond Halley Gallery houses the most important assemblage of astrolabes in the world. Here can be



Overlooking the Thames River, the Royal Greenwich Observatory, found examples of all kinds of models of the heavens, armillary spheres, astrolabes, orreries, planetaria, and celestial globes, all of which served to demonstrate the motions of heavenly bodies.

In the Nevil Maskelyne Gallery, the displays mostly relate to the finding and keeping of time without the aid of clockwork. Shown are a great variety of sundials. Those close to the windows are set up so that when the Sun is out, they tell the time. Sundials in the courtyard area can be considered a part of this collection.

The Nathaniel Bliss Gallery tells about the history of the *Nautical Almanac* as it relates to the data compiled for it at Greenwich. Hourglasses, as well as "nocturnals" (which permitted the finding of time by night through the plotting of the position of certain circumpolar stars) may be examined closely.

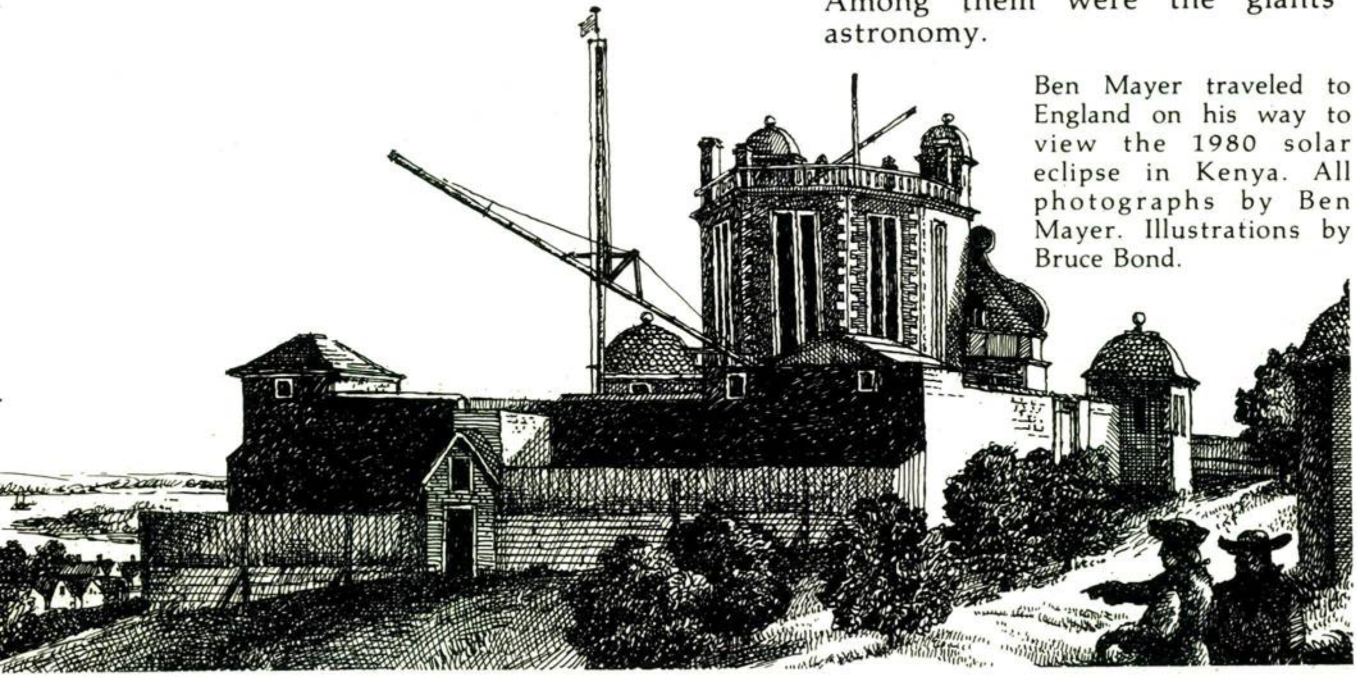
The Spencer Jones Gallery introduces the dimension of mechanical and electrical timekeeping. A special section covers the development of the spring detent escapements for marine chronometers. The original motor-driven Gate clock by Shepherd can also be seen here.

To capture the ambience of the earliest days of Flamsteed House, several of the seventeenth century living rooms have been sensitively recreated. By drawing on the almost unlimited resources of period furniture and furnishings which are housed in the Victoria and Albert Museum in South Kensington, contemporary environments have been restored. A dining room, study, a library — even a bedroom — are shown much as they would have appeared when Flamsteed and his family occupied them. The fireplaces must have been welcome during cold London nights when fog, clouds, or rain made observation impossible.

After World War II, when smoke and light pollution had made London and its Greenwich park unfit for the purposes of astronomical observation, the Royal Observatory (renamed the Royal Greenwich Observatory) left the historic premises and moved to Herstmonceux Castle in Sussex. There the work and the traditions of the old observatory are being continued in modern facilities amidst idyllic surroundings.

The low ceilings or doorframes might suggest men of shorter build. Still, a visit to the old Royal Observatory in Greenwich brings home the true stature of those who labored here. Among them were the giants of astronomy.

Ben Mayer traveled to England on his way to view the 1980 solar eclipse in Kenya. All photographs by Ben Mayer. Illustrations by Bruce Bond.



brought into being by command of King Charles II, as it was in 1680.

VOYAGER APPROACHES
SATURN

The remarkable remote sensors aboard the Voyager 1 spacecraft have been scanning Saturn and the saturnian system during the six months prior to November 12 flyby encounter, and they have produced interesting new data. Because the flyby itself is so rapid, the Voyager mission strategy has emphasized prolonged preliminary observations to establish a context for interpretation of flyby data. If atmospheric imaging, for example, were done only at flyby, the result would be a static "snapshot" rather than the far more informative and dynamic "movie" that Voyager has produced.

On a routine seven-times-per-day basis, the ultraviolet spectrometer has examined the planet for telltale signs of hot gas in the Saturn system. A ring of hot hydrogen, such as some astronomers expect to find in Titan's orbit, could be detected by these observations. Jupiter's volcanically active satellite Io orbits in a ring of this type made of hot sulfur and oxygen ions from its volcanos. Titan's atmosphere would provide the source for such a hydrogen ring.

The infrared spectrometer and radiometer have been gathering daily information on the composition and temperature of the atmospheres of Saturn and the temperature of the rings and satellites.

The planetary radio astronomy instrument, returning data twice daily, has provided one of the first concrete results of the Saturn mission: a redetermination of the rotation period of Saturn itself. Saturn's cloud layers have provided little in the way of spots and features for ground-based observers to time, and the clouds themselves are moving at different speeds at different latitudes and thus do not represent the rotation of the bulk mass of Saturn. The period of rotation of the clouds is around 10 hours 14 minutes. Voyager radio scientists at NASA's Goddard Space Flight Center have been analyzing the bursts of non-thermal *radio* noise from Saturn since it first became possible to distinguish Saturn's radio signals from the greater radio noise of Jupiter. Assuming that the non-thermal radio emissions are produced through magnetic interactions "tied" to the bulk of Saturn, Saturn rotates in 10 hours 39.4 minutes, with an uncertainty of about 10 seconds.

Another important observation made late in September was a check on Einstein's General Theory of Relativity. At that time, the Voyager spacecraft was in conjunction with the Sun, and its radio signals passed approximately 2° from the Sun. Solar gravity should have produced a slight delay in the signals if General Relativity is correct — a delay of about 10^{-4} seconds in the 83-minute radio signal trip. Since the round-trip time can be measured to an accuaracy of 10^{-7} seconds, General Relativity will be subject to a precise test when the data are reduced.

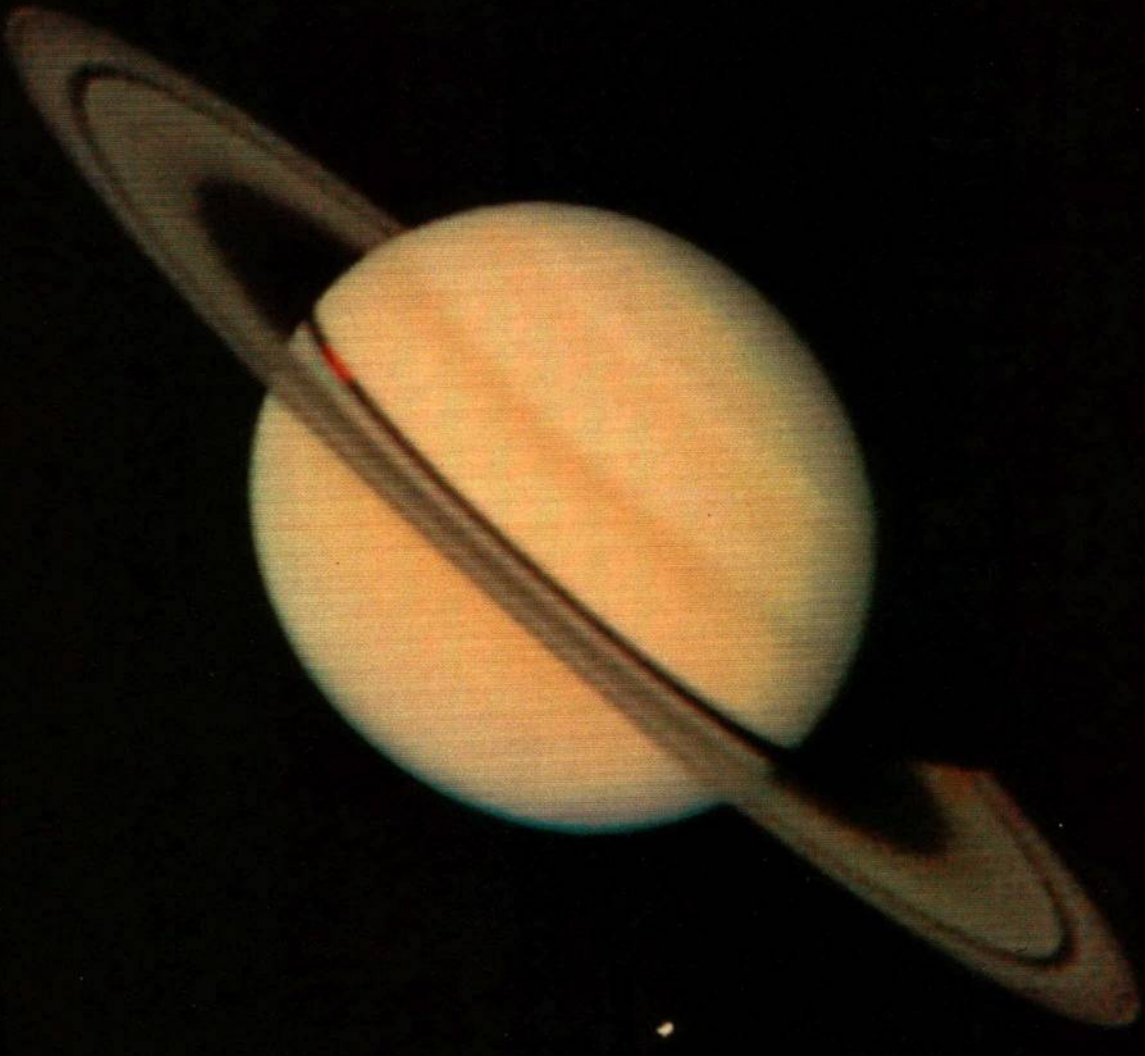
Voyager's cameras have provided another of the ongoing sequences of observational data. Every 2 hours 3.2 minutes, the cameras have taken five frames of Saturn pictures through color filters, thus providing five overlapping color time-lapse "zoom" movies of Saturn's atmospheric activity. In addition, pictures to search for undiscovered and suspected close satellites have been taken three times each day. It could be many months before scientists have time to search all the frames in detail before the satellites, if any, are found.

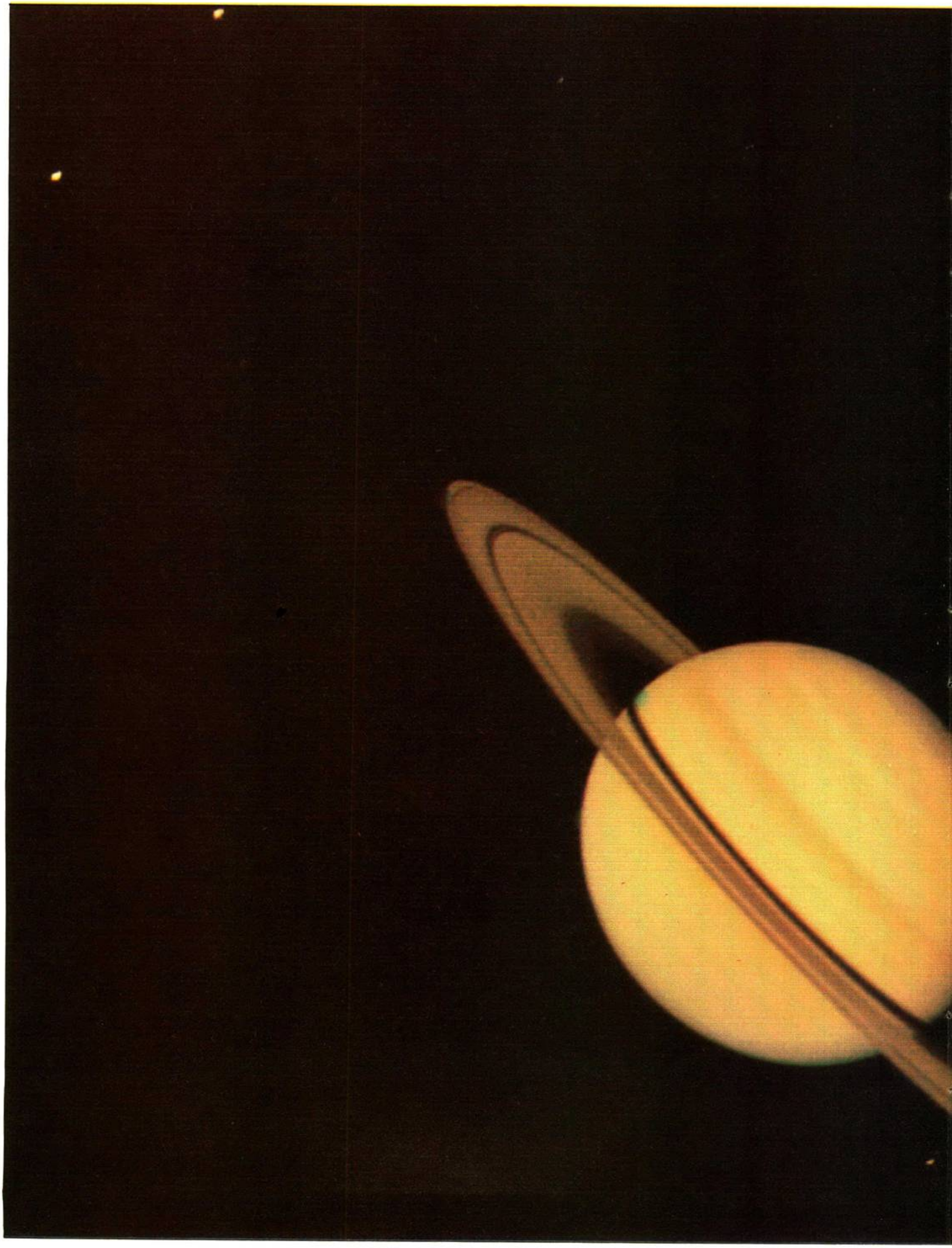
A similar search for jovian satellites has raised the count of Jupiter's moons to 16 (or possibly 17), and more may yet be found. Saturn, which has long been suspected of harboring a large number of small moons close to the rings, offers great promise of showing more.

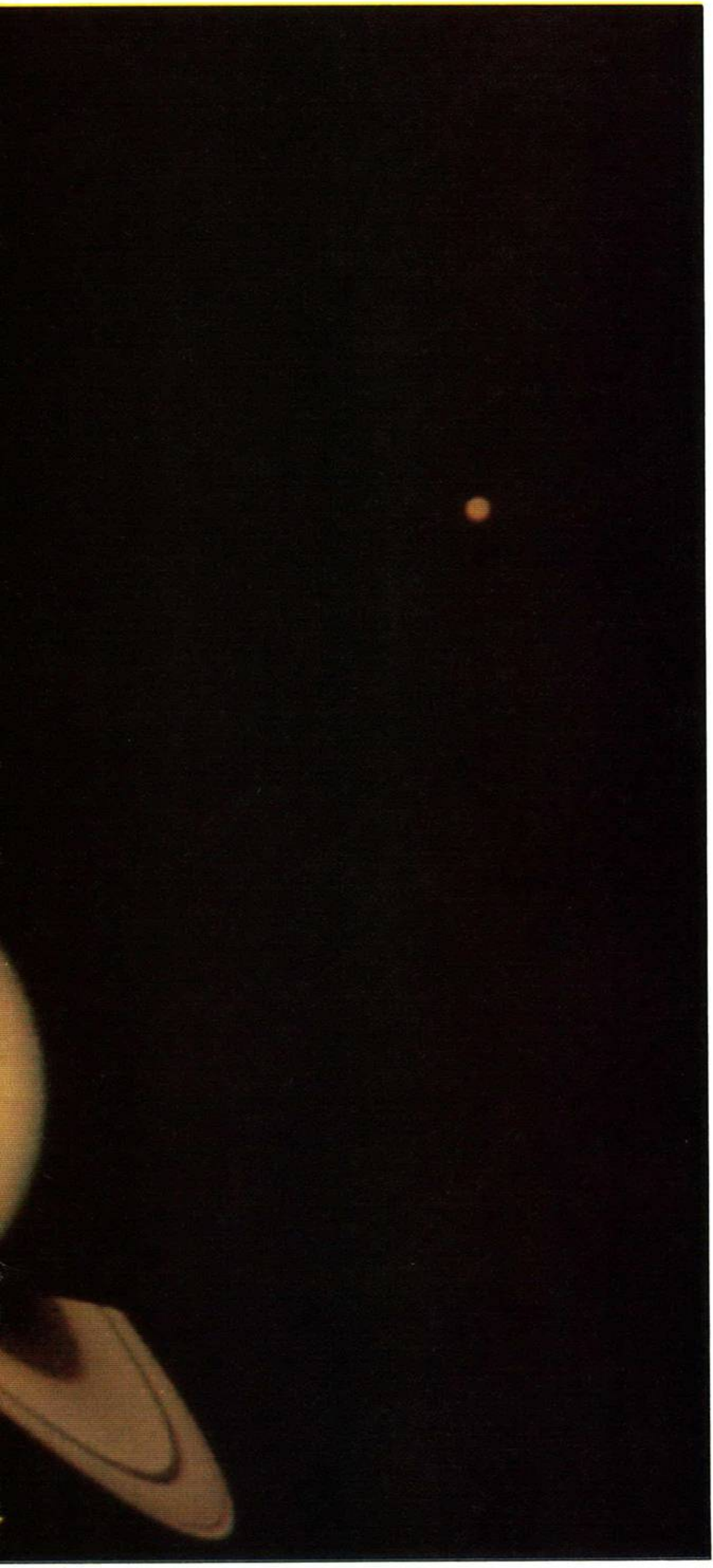
The photographs of Saturn itself have been steadily improving in detail as Voyager approaches the planet. From a range of over half an astronomical unit (the closest picture available for this issue of ASTRONOMY), the pictures have shown rather unexpected structural detail in the rings. Cassini's Division has shown clearly since the earliest pictures, but the detail inside Cassini's Division (best seen near

From 66,000,000 miles out, a considerable amount of structure can be seen in the rings, and dark and light cloud bands are visible through a whitish *high-altitude haze. Two satellites are* visible: Enceladus, to the left of the rings; and Dione, just below Saturn. This photo was taken 80 days before encounter, on August 24.

NASA/JPL

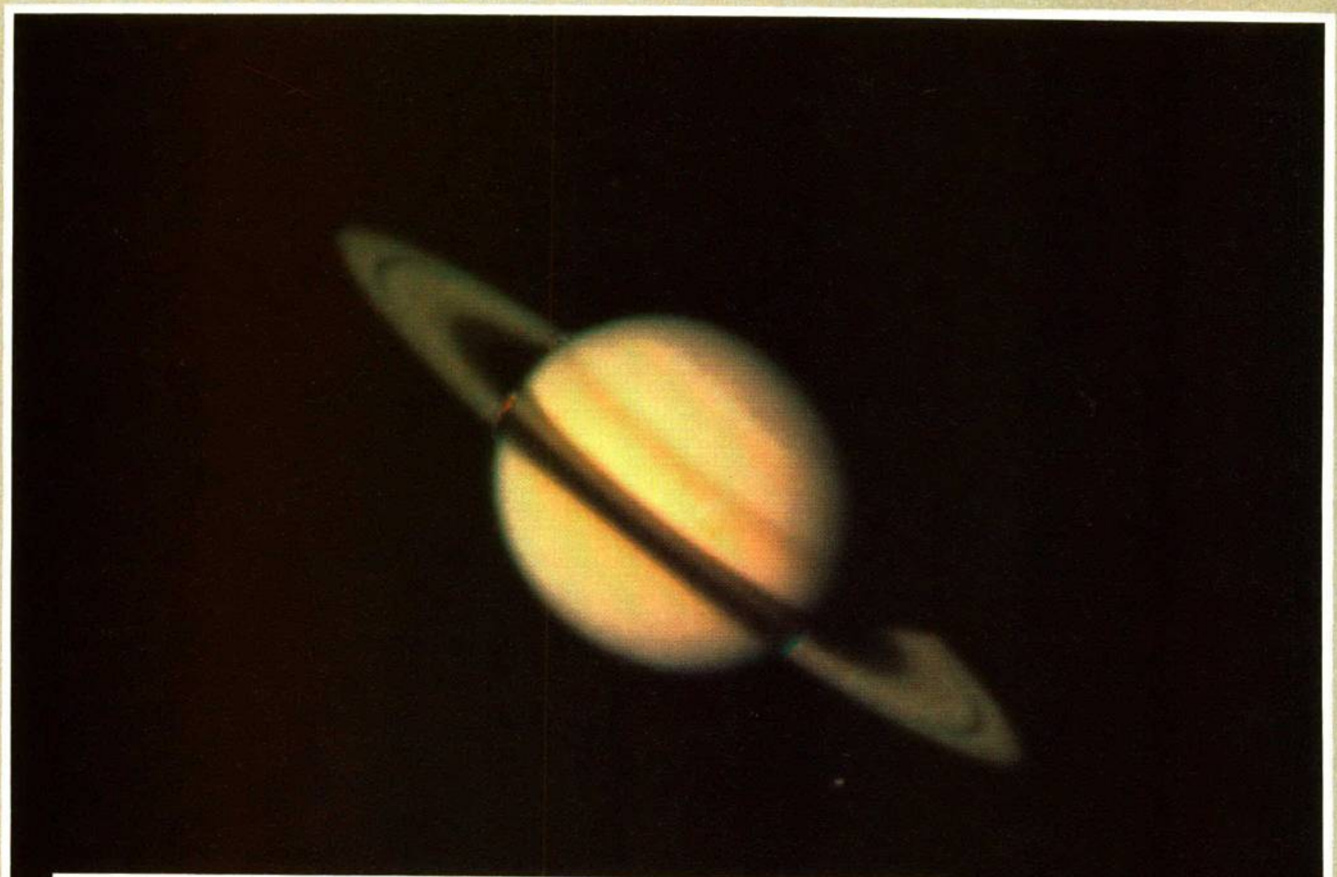




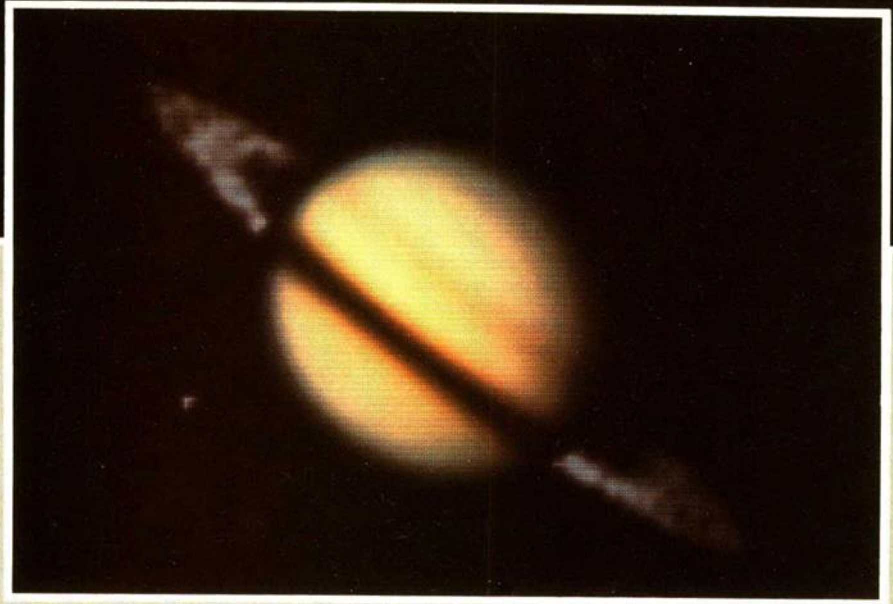


NASA/JPL

Closing in on Saturn, but still 56 days and 47,000,000 miles from it, the Crepe Ring now shows clearly just inside the B Ring, and Cassini's Division shows hints of internal detail. Cloud structure is just becoming visible. Saturn's largest satellite, Titan, showing as a tiny orange disk, appears in the upper right corner. Four smaller moons are arrayed around the planet. The resolution of this picture is about 1,000 miles.



Slightly exceeding the resolution of the best Earth-based images of Saturn, Voyager's June 24 photograph from 116,000,000 miles shows details as small as 2,200 miles across. Saturn's ring appears rather dim in this image because it was taken when the Sun was shining on the rings at the grazing angle of 1.9°. Tethys is below and to the right of Saturn.



NASA/JPL

On March 20, 1980, Voyager 1's powerful television camera photographed Saturn from a range of 194,000,000 miles. This image, which filled only a tiny part of the camera's field of view, has been computer enhanced. To the lower left of Saturn is its satellite Rhea.

the ansae) has been a surprise. Low contrast fine detail is also visible in the A-ring and the B-ring.

Saturn's rings, seen under low solar illumination, are brightening as the solar angle has increased due to Saturn's motion in its orbit. The Crepe Ring, invisible in the earliest pictures, is readily visible in the picture from half an astronomical unit.

Only the lack of dramatic and colorful cloud detail on Saturn has been disappointing. Saturn has a high-level whitish haze in its atmosphere that obscures lower level features perhaps as colorful and dramatic as Jupiter's. At first glances, only a pale banding is visible through the haze. Consisting of particles of frozen gases, the haze is present because Saturn is nearly twice as far from the Sun as Jupiter, and its upper atmosphere is colder. As Voyager approaches Saturn and resolution of the pictures increases, however, the images suggest that low contrast features besides the banding *are* present and Saturn's atmospheric dynamics will not remain unseen under a dull layer of haze.

The next issue of ASTRONOMY will contain a full report on the flyby of Saturn by Voyager 1.

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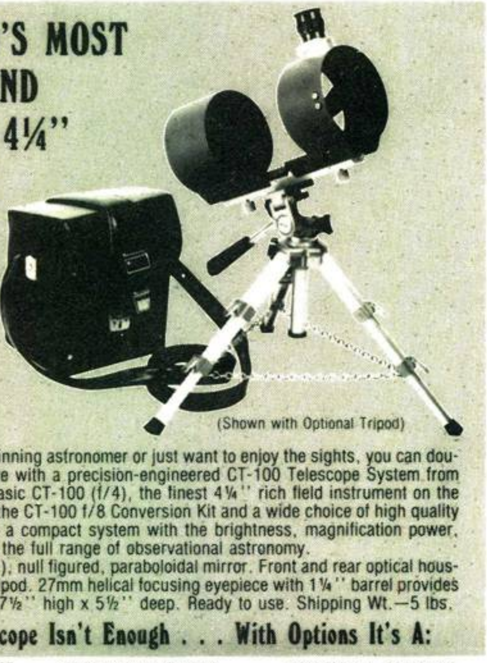

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ASTRONOMY FORUM

Closer to Creation: the 10-Meter Telescope

Each time a larger, more sophisticated telescope has been built, the frontiers of our knowledge about the universe have been pushed farther back. Now, the University of California is in the advanced planning stage for a 10-meter optical/infrared telescope, probably to be installed on Mauna Kea. Three committees — scientific, site selection, and technical design — will soon be submitting their final reports to University officials. Then, the goal will be to find funds for the project.

ASTRONOMY interviewed Dr. Sandra Faber of Lick Observatory, head of the science committee. She began by discussing the debate over the mirror design of the telescope, which was finally settled by a committee of astronomers chaired by Lick Director Donald E. Osterbrock. The committee considered two designs: a single, monolithic 10-meter mirror and a "snowflake" cluster of about 60 adjacent hexagons, each 1.4 meters across. They chose the segmented design.

FABER: What people were finally deciding on at the end was not time or money (which were ostensibly the original reasons for picking one approach over another), but the probability of success of the two approaches. And the people who decided that segments were the way to go thought that the risk of breakage of the single-piece mirror was just too great. Also, supporting it adequately was still basically an unsolved problem.

ASTRO: Has ten meters been the proposed size all along?

FABER: Yes, at the very outset we were thinking ten meters.

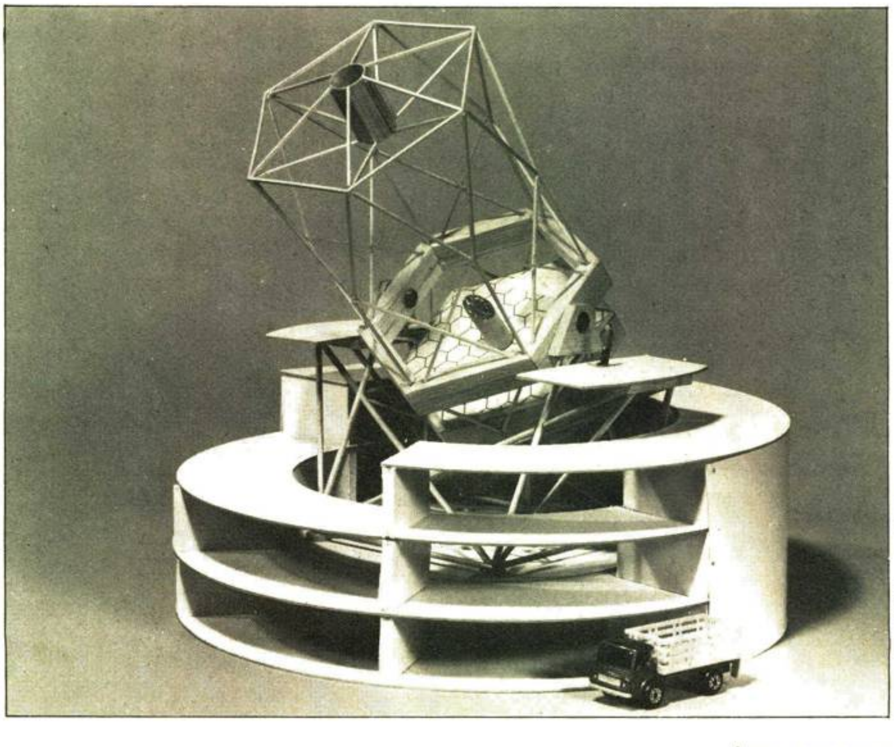
ASTRO: Why?

FABER: Because it's a factor of two bigger than the largest telescope that really works, the 200-inch, which is five meters. This is a totally seat-of-the-pants argument, but if you asked astronomers: "At what point does an increment in aperture mean a real qualitative difference in the kind of science that you can do?", they would say it's at the factor of two level. You could not do with a 60-inch telescope what we do with the 120-inch — it's just too big a difference. For the 120-inch to try to keep up on a photon-to-photon basis with the 200-inch is very difficult — and that's almost a factor of two increase.

ASTRO: If your telescope is twice the size of the one at Palomar, you'll have four times the light-gathering power...

FABER: ...and at the same time, we plan to go to an excellent site, where the seeing will be about twice as good as it is at Palomar. Increasing the power of this telescope is a multi-faceted attack: a bigger mirror, a better site, and cleverly-designed instrumentation for higher efficiency. When you put all those things together, it's realistic to think about more than a factor of four gain in speed. It'll be more like a factor of ten — and at that point, what you could do becomes extremely exciting.

ASTRO: What sort of research will the 10-meter be able to do that our present telescopes can't?



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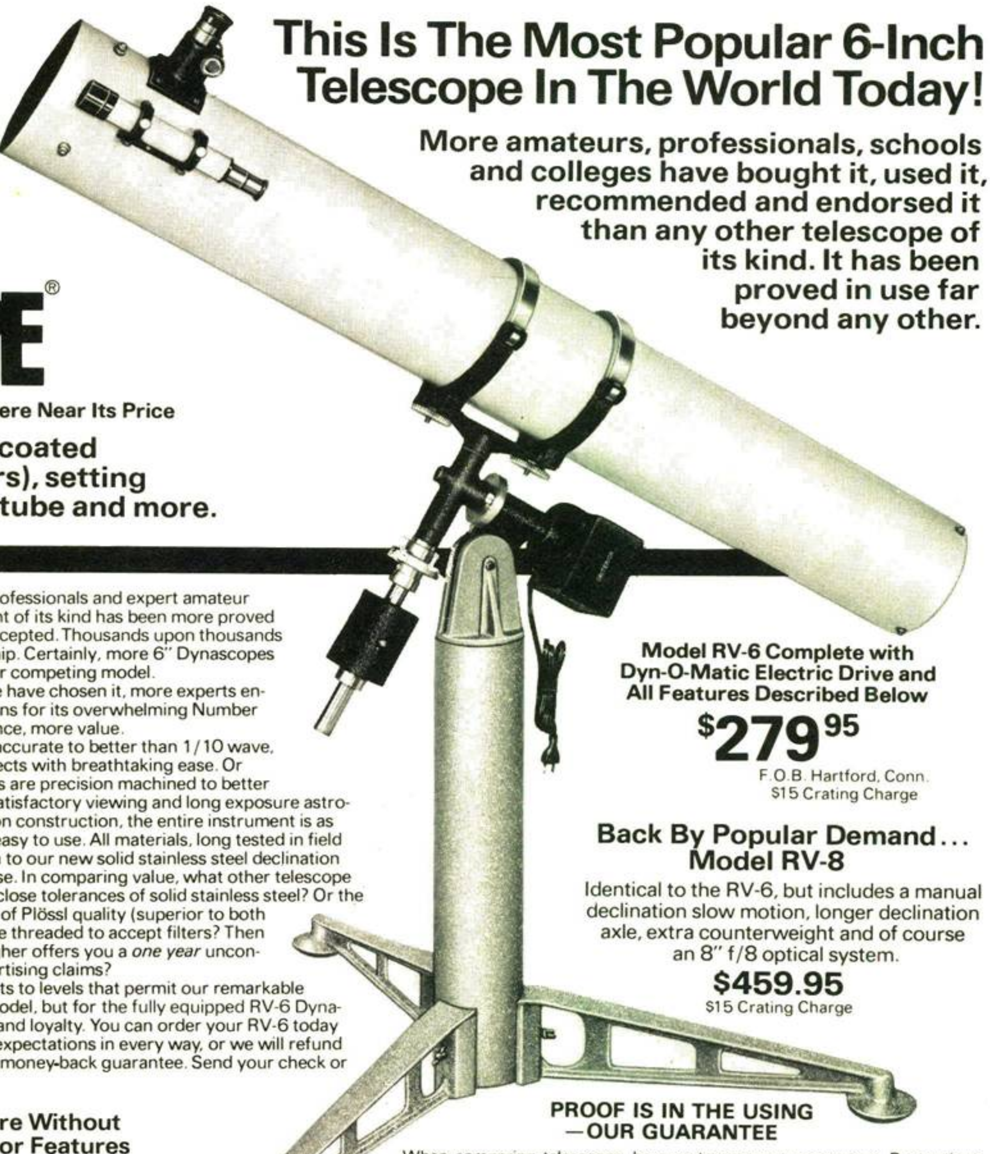

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FABER: The 10-meter telescope is going to be a fascinating tool for studying very, very distant galaxies and galaxy evolution. We're getting to the point now where we're just able to detect galaxies out to a red shift of one. That corresponds to a look-back time of something like 60 percent of the age of the universe. That's six to ten billion years depending on how old you think the universe is.

ASTRO: You say "detect." You mean we can't really analyze these galaxies with existing equipment?

FABER: Right. The idea of this big telescope is to be able to take good spectra of these things. We'll be taking detailed spectra of galaxies that you can't even see on the *Palomar Sky Survey* plates.

ASTRO: So we'll be able to study the composition of galaxies as they were maybe ten billion years ago, and...

FABER: Yes, by comparing those distant galaxies with nearby galaxies, we're going to be able to see what changes have taken place over a six to ten-billion-year period. There are some scenarios that say that galaxies were just forming six to ten billion years ago. Well, if that's true, we ought to see them as very bright and youthful blue objects. But if we look and see galaxies that are very red, or more evolved, we'll know that they must have formed even billions of years eariler. I would like to know whether the galaxies formed right after the Big Bang or relatively recently.

ASTRO: So we're lucky that the speed of light is finite! Otherwise we'd see everything as it is right now; we wouldn't be able to look back into time and follow this evolution.

FABER: And there's another thing: Most galaxies are members of groups. There are very few really isolated galaxies. Astronomers now think that this clustering was caused by the fact that way back at the Big Bang there must have been lumps of higher density than other lumps. As as a result, the higher-density regions attracted matter and became the big clusters today. Lower density regions might be places where we see isolated galaxies. Well, clustering takes time to develop. Something that looks like a big dense cluster today, billions of years ago would have just been forming. So as we explore the structure of the universe billions of years ago, we expect to find the inhomogeneities to be a lot less, because they hadn't then had *time* to develop. Not only will we look at the evolution of galaxies, but we should be able to follow the formation of clusters of galaxies. That's going to tell us a lot about what the amplitude and nature of the original inhomogeneities — the ones that made galaxies and galaxy clusters — were really like. Nobody understands that now.

ASTRO: What research besides that on galactic evolution will be done?

FABER: Another spectroscopic project that is really important is metal abundances of faint stars in our Galaxy. We're just now getting to the point where some astronomers have measured element-by-element abundances in the globular clusters of our own Galaxy. Globular clusters are very important as kind of microcosms of the early history of our own Galaxy, especially the galactic halo. Understanding how star formation took place in them, and what their structure looked like, is critical in understanding the structure of our own protogalaxy when it was collapsing. Since globular clusters are generally pretty far away, right now the bright K giants are at the limit of existing telescopes. We just can't go any fainter than that.

But some fascinating things have already emerged. The element abundances vary from star to star in puzzling ways. To some extent, they can only be explained by arguing that all the stars in a globular cluster did not have the same metal abundance when they formed — that they weren't made out of homogeneous material.

ASTRO: Is it as simple as saying that the stars near the center of a cluster are metal-rich, and ones on the outside are metal-poor?

FABER: Some people have actually claimed to see evidence for something like that. But it's only going to be resolved to everybody's satisfaction when abundance studies of stars on the main sequence can be done. The atmospheres of the type K giants are all messed up from extensive nucleosynthesis. Their atmospheres don't reflect the elements that went to make up the star originally. The atmosphere of a dwarf star, however, really should be an example of the primordial material from which the star was born.

ASTRO: And now the main sequence dwarfs are...

FABER: ...too faint, see? But they would be within reach of a telescope like the 10-meter. That's just one of the really crucial problems that are just below the threshold of existing telescopes. With that factor of ten increase, wow, you'd really be off and running!

ASTRO: Will there be any advantages from the 10-meter being in Hawaii, and farther south than most large telescopes?

FABER: Yes, that's going to be a tremendous benefit. One object we'll be able to reach is the galactic center. Even though you can't see the galactic center in the optical, the higher angular resolution of the 10-meter telescope will mean that we can really study the dynamics of the very central part of the Galaxy. For example, Charles Townes, an astronomer, and his group think that there could be a black hole of about 10^7 solar masses right in the galactic center. They just don't have the angular resolution to prove that it's truly a black hole, rather than some dense star cluster. With a 10-meter telescope, you'd be able to make these measurements and say — for sure — whether it's just stars or really a black hole.

We'll also be able to study the general stellar population of the galactic bulge, which is highly interesting to people like me. I've sort of made my living studying stellar populations in elliptical galaxies. Since the central bulge of our Galaxy has photometric colors very much like an elliptical galaxy, but it's close enough that we can dissect it star by star, it's the only example we have where we can study an elliptical galaxy star population on a star-by-star basis.

ASTRO: So you feel that Mauna Kea would be a very good location for the 10-meter.

FABER: I think Mauna Kea is absolutely the best place for this telescope! It combines the good seeing necessary to really make the telescope work optically with the altitude necessary to realize its full potential as an infrared telescope.

ASTRO: Because at high altitudes there's less water vapor to absorb the infrared?

FABER: Right. Mauna Kea is an amazing astronomical resource. I'm

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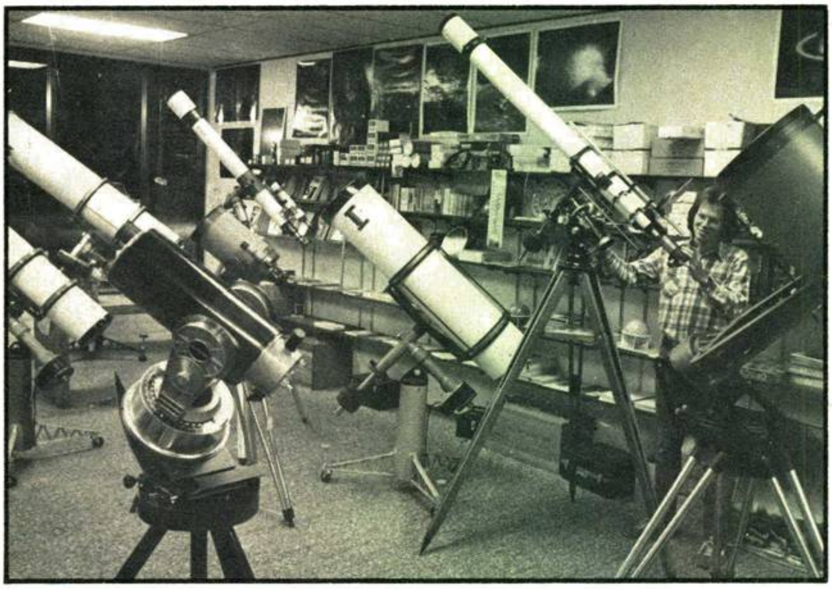

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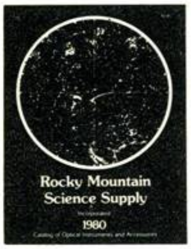

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delighted that the State of Hawaii has set it aside as an astronomical preserve.

ASTRO: It can't be perfect, though. The winds, for instance...

FABER: Mauna Kea is an extremely windy place. Unless we're quite careful, the telescope will be jostled very badly by winds. You'd like to protect it against wind problems by making a very big dome and burying this little telescope inside it. We can't do that because the dome will be too expensive if we make it big. And the other reason we don't want to do that is there's good evidence from the Multiple Mirror Telescope that shows the more nearly the telescope comes to sitting out in the open air, the better the seeing is. If the inside of a dome gets warmed up during the day by the sunshine, and at night there's only a small slit to let it cool, the dome will tend to stay too hot. If you make the slit wider and let everything in the dome radiate to the open sky, you tend to come into equilibrium fast with the cool outside nighttime environment. When you stand beside the MMT, you feel as though you're outside because the slit is so very wide. If you put the telescope out in the open air as much as possible, it means using a small dome and a wide slit.

ASTRO: But then you're also exposing the telescope to the winds more.

FABER: That's right. So the crucial design question is: Can we make the telescope structure stiff so that even though we're observing into the teeth of a thirty-mile-an-hour wind, we're still not going to be buffeted around?

ASTRO: Well, can you? Even with an open-frame telescope, how do you make it that stiff without it being too heavy?

FABER: The basic philosophy is that all structural members are used either in compression or tension. In a normal telescope, many members are in torsion. Things are usually torsionally not very stiff, so you're forced to make their masses large.

ASTRO: So one goal with the 10-meter will be to eliminate the usual twisting motions that necessitate the mass.

FABER: It's like a geodesic dome — all the members are either pulled or pressed. That way they're stronger and therefore can be lighter. The net result is that the moving weight of the 10-meter is planned as less than half the Kitt Peak 4-meter's weight!

ASTRO: The segmented mirror design must have its own unique challenges.

FABER: The problem of getting the focal lengths of all the segments the same — well, we're still struggling with that. That's not usually a problem in making an astronomical mirror. You want it to be a beautiful parabola, say, but you usually don't care whether the focal length of that parabola is here or here or here. As long as it's within rather broad tolerances, it's okay. Suddenly, we've added a totally new constraint: not only must the surface be a parabola, but it must be a particular parabola.

ASTRO: But it's just a matter of regrinding the mirror until it's accurate, right?

FABER: Right, but it's how many times you have to do it. Time equals money.

ASTRO: And the original design called for about 60 segments!

FABER: Yes, but in fact we may go to slightly larger segments, and fewer of them. More like 35.

ASTRO: Dr. Faber, you've stressed the spectroscopy. If you took away spectroscopy, could you still justify this telescope?

FABER: I think if you took away spectroscopy, you couldn't justify any optical telescope. That's why the optical is such an important part of the spectrum: because you can do spectroscopy. Futhermore, you can do spectroscopy on virtually every kind of object in the universe, because every object either radiates in the optical and infrared wavelengths (and let's include infrared because we do infrared with the same telescopes), or is associated with an object that does. For example, Cygnus X-1, the black hole candidate, can't be seen. But it does have a visible companion source, and without that, we wouldn't know anything about it.

ASTRO: The imminent creation of the Space Telescope doesn't affect your feelings about the necessity of the 10-meter?

FABER: A lot of people have said: "We're going to build the Space Telescope anyway. Why should we build this new big telescope to do the same job?" The thing that the 10-meter telescope can do — which is unique — is to get good spectra. Spectroscopy requires collecting lots of photons. With an ordinary sized telescope, there just aren't enough photons. Even when there are enough photons to get a good image, by the time you spread them out into a spectrum, there aren't enough to get a good spectrum.

ASTRO: So the 10-meter and the Space Telescope will complement each other.

FABER: Very much. I think this telescope is vitally needed as a back-up to Space Telescope.

ASTRO: That's a strong argument against the point of view that once we have the Space Telescope...

FABER: ...we won't need anything else. No, it's quite the opposite. There's a crying need for spectroscopic instruments. The Space Telescope sees all these little blobs of light. They look interesting, but what are they? Are they distant galaxies? Are they faint stars? If they're galaxies, how far away are they? You must have a spectrum to answer questions like that.

ASTRO: So when they find a faint point source with the Space Telescope, until we build something like the 10-meter...

FABER: ...there won't be any telescope on Earth big enough to take a spectrum of it.

ASTRO: Do you feel, then, that we should not pursue space astronomy aggressively?

FABER: I would never want to discourage a move into space. I'm all in favor of space astronomy if the American public is willing to pay for it. But a 10-meter telescope in space would be the most expensive space project ever contemplated by the American people. On the ground, it's cheap by space standards.

ASTRO: Do you think we should have more large ground-based telescopes now?

FABER: Yes. I think it's the best thing to do. But ultimately, I am certain, we'll be going into space.

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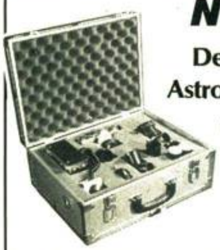

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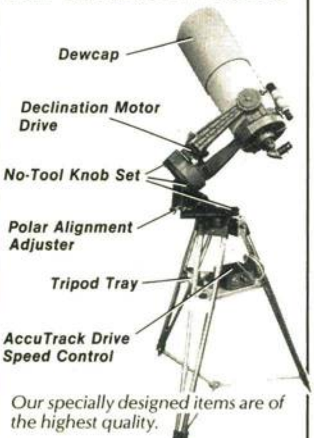

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eye
on the
sky

farewell to autumn

by
Fred Schaaf

the wanderers

At the beginning of December, four of the five bright planets are visible in the pre-dawn sky, but two of them — the already close pair of Jupiter and Saturn — are also now within range for late-night observers.

For early risers this will be the last month to see **Venus** in full darkness, because by the last day of 1980, this brightest of all planets will be rising just before the beginning of morning twilight. At magnitude -3.4, Venus is less brilliant than usual, but still far outshines the best that the other planets can ever achieve. This yellowish planet passes exceedingly close to Beta Scorpii (magnitude 2.9) on the morning of December 20, when it will be less than one-third of a degree north of the star. This unusual conjunction should be visible to you if your skies are quite clear that morning.

Neither Mercury nor Mars will be easily observable this month. Early in December, you might glimpse orangish **Mercury** low in the southeast about an hour before sunrise, but on the 31st, it is on the verge of passing behind the Sun. On the 28th Mercury makes a rare central crossing of M-28, a globular star cluster in Sagittarius, but this would be a telescopic event even if the objects weren't much too close to the Sun to observe at all. **Mars**, the only planet currently in the evening sky, continues to be marginally visible low in the southwest before setting just at the end of twilight.

Jupiter and **Saturn** are a fine pair rising together a little after 1:30 a.m. as December opens, and thereafter progressively earlier in the night until, on New Year's Eve, they will be coming up almost exactly on the stroke of *midnight* for viewers around 40° N. latitude.

All month Jupiter will be creeping closer to slow Saturn, brightening until it outshines the brightest stars. Saturn will be many times dimmer, about equivalent to the star Spica which rises a while after these planets and is not too far to the southeast. Although Jupiter, at month's end, is spectacularly close to, and southwest of, Saturn, Saturn itself has an even closer companion in the opposite direction: the famous double star Gamma Virginis (Porrima).

Next month, Jupiter and Saturn have the first conjunction in their "Great Conjunction" — a series of three meetings. Such conjunctions occur very rarely. Although a conjunction of Jupiter and Saturn (or the entire Great Conjunction) in 7 B.C. has been suggested as a candidate to account for the Star of Bethlehem, there are several other equally compelling theories.

One more planet and its satellite are of special interest this month: the **Earth** and **Moon**. At 11:56 a.m. on December 21, the Earth reaches the Winter (or December) Solstice so that for people in the northern hemisphere, days are now shortest and the lowest Sun of the year shines in the constellation Sagittarius. This year, the Full Moon occurs only a little more than an hour after the Winter Solstice. Since the Full Moon is opposite the Sun, we therefore see this month's Full Moon at almost the very highest possible — on the border between Taurus the bull and Gemini the twins. In the a.m. hours of the 29th, the waning Moon has a medium close, but still very pretty, conjunction with Jupiter and Saturn.

The most spectacular special event in the December heavens may come from another type of solar system body, the **Geminid** meteors. These moderately-swift shooting stars radiate from high in the southern sky from midnight until early morning on several nights around December 14, on which date as many as 50 or 60 meteors per hour might be seen by an observer with dark skies. A far less famous meteor shower, the **Ursids**, which come from Ursa Minor, are at their best on the night of December 21-22, but will be spoiled by the Full Moon. Yet the north sky may still bear watching that night, because the parent comet of these meteors, **Comet Tuttle**, will have passed through that neighborhood of space just a few weeks earlier.

the starry sky

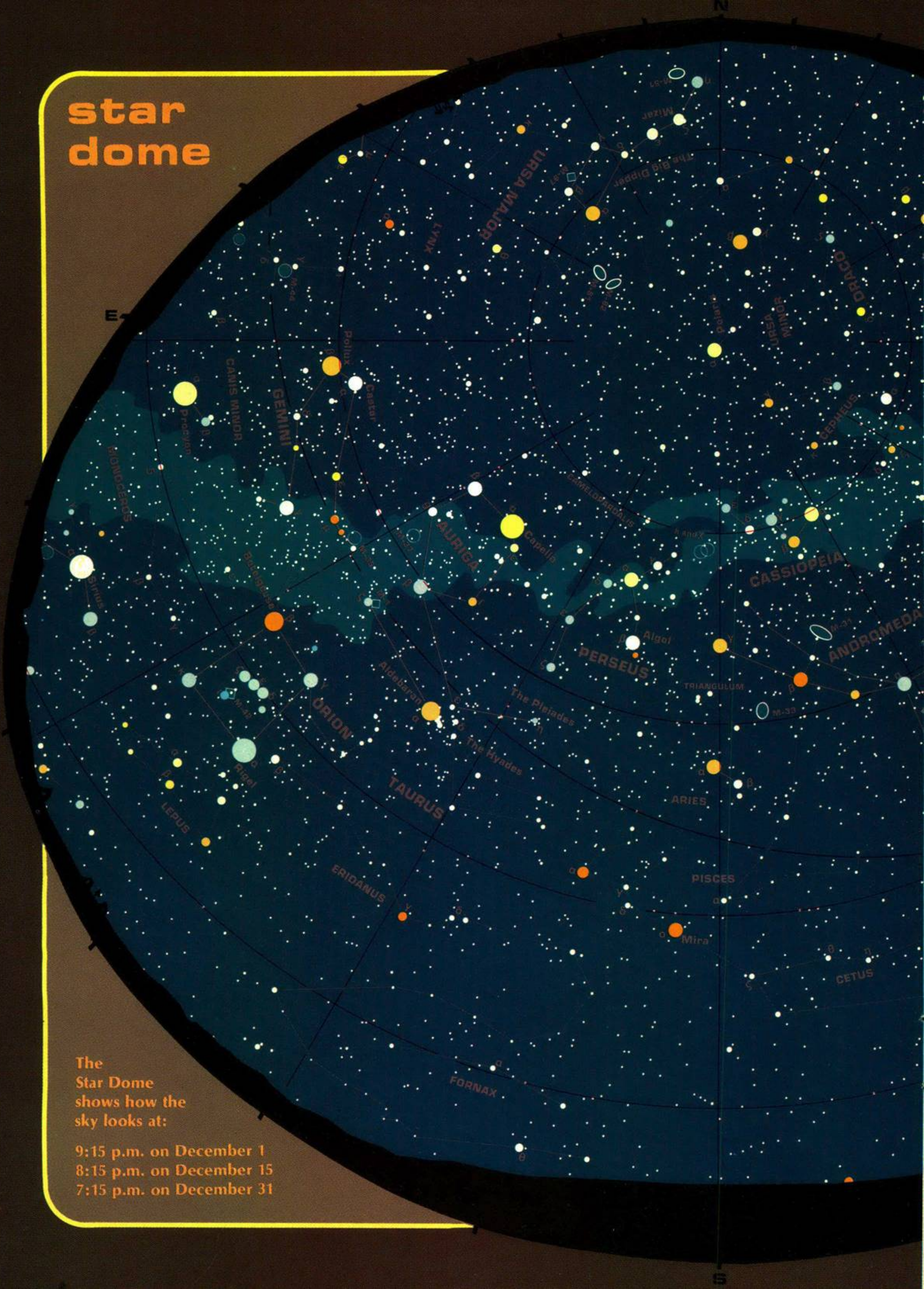
As our nights grow longer and longer, the early evening hours are still occupied by the constellations of autumn. By the middle of the evening, however, the eastern sky is filling with a superb array of first and second magnitude stars, and we know that the chill but brilliant nights of winter are arriving. This rising host of bright patterns is very alluring.

But first things first: the last constellations of autumn now hang high overhead, and you would not want to neglect best views of such sights as striking Perseus or that most lovely and myth-honored of star clusters, the Pleiades.

In mid-evening, the last of the summer stars, **Deneb**, is low in the northwest, standing at the top of the upright **Northern Cross** (known as Cygnus the swan). The soft-glowing Milky Way flows from around Deneb and climbs high in the north where you will find it surrounding the very prominent pattern which at this time looks like a rough letter M: **Cassiopeia**

Relatively modest equipment can be used to take impressive astrophotographs. Terrance Quataert of Rochester, New York, combined an Astroscan with a T-*adapter and a Barlow lens* and used a 35 mm camera with Ektachrome film at 1/125 second to capture two phases of the partial lunar eclipse on August 25.

star dome


N
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URSA MAJOR
The Big Dipper
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M-81
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LYNX
M-44
Polaris
URSA MINOR
DRACO
CEPHEUS
CAMELOPARDALIS
CASSIOPEIA
ANDROMEDA
M-31
M-33
TRIANGULUM
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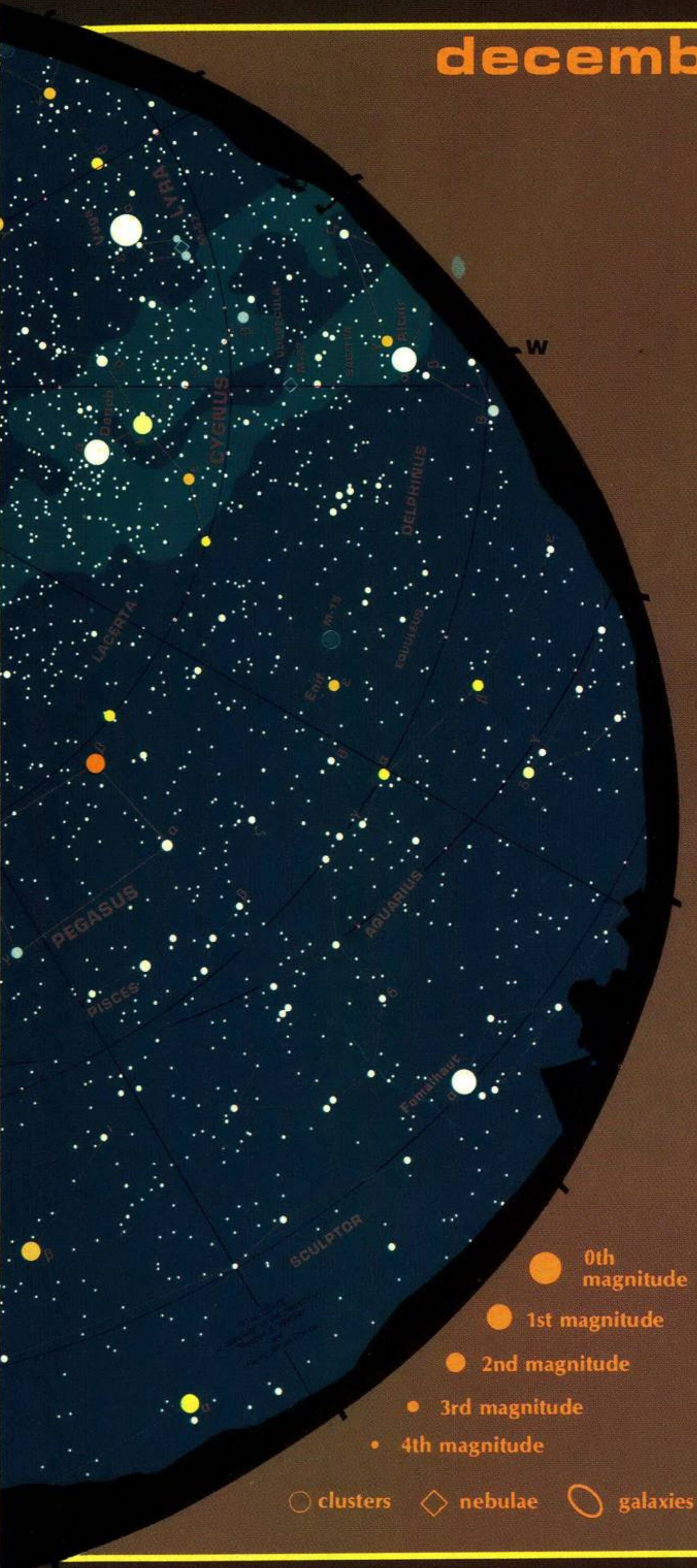
h and χ
Capella
AURIGA
Pollux
Castor
GEMINI
CANIS MINOR
Procyon
MONOCEROS
Sirius
Betelgeuse
ORION
M-42
Rigel
LEPUS
Aldebaran
The Pleiades
The Hyades
TAURUS
ARIES
PISCES
Mira
CETUS
ERIDANUS
FORNAX

The Star Dome shows how the sky looks at:

9:15 p.m. on December 1
8:15 p.m. on December 15
7:15 p.m. on December 31

december sky almanac

1st	Moon will be near Jupiter and Saturn in the east before sunrise this morning.
2nd	Moon farthest from Earth (apogee) tonight at 11 p.m. EST: 252,054 miles.
4th	A crescent Moon will be above Venus in eastern sky before sunrise.
7th	New Moon: 9:35 a.m. EST.
9th	Mars lies to the south of the Moon in the evening sky.
11th	Mercury will be near the star Antares shortly before sunrise this morning.
13th	Tonight and early tomorrow morning look for the Geminid meteor shower. Best watching comes from midnight until dawn — so bundle up!
14th	First Quarter Moon: 8:47 p.m. EST.
18th	Moon closest to Earth (perigee) at midnight tonight: 226,390 miles.
19th	Moon will be close to the star Aldebaran when it rises tonight.
21st	The solstice happens at 11:56 a.m. EST today — first day of winter. Also, Full Moon at 1:08 p.m. EST.
22nd	Ursid meteors reach their peak tonight and early tomorrow morning, but the Full Moon will interfere badly.
25th	Venus will be near the star Antares shortly before sunrise this morning.
29th	Last Quarter Moon: 1:32 a.m. EST. Also, it will be near Jupiter and Saturn.
30th	Moon at apogee (farthest from Earth) at 6 p.m. EST: 251,499 miles.
31st	Mercury at superior conjunction — moves into evening sky.


LYRA
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Deneb
Altair
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LACERTA
M-15
Enif
EQUULEUS
PEGASUS
AQUARIUS
PISCES
Fomalhaut
SCULPTOR
0th magnitude
1st magnitude
2nd magnitude
3rd magnitude
4th magnitude
○ clusters
◇ nebulae
galaxies

the queen. This familiar constellation consists primarily of second magnitude stars and is not far from two other bright star patterns which share in her famous myth.

The larger of these is **Pegasus** (the flying horse) which lies south (high in the southern sky) from Cassiopeia and includes the landmark (or might it be skymark?) of autumn, the **Great Square**. The brightest star of the Square forms, with two others to the east, the main line of the queen's daughter, **Andromeda**. Before leaving these, be sure to go up past two dimmer stars from the middle bright one and look again at that mysterious elongated glow of hazy light: the **Great Galaxy of Andromeda**. The light you see tonight has been traveling since before mankind began. The galaxy is composed of billions of wheeling stars.

Below Andromeda, take at least a brief look at the aptly named **Triangulum** (the triangle) and the similarly little **Aries** (the ram). Down still farther run the dim strands of **Pisces** (the fish) and the large form of **Cetus** (the whale) with his rather conspicuous pentagonal head and a second magnitude star on either end of his long east-west extent. The brightest star in the head, now at its highest, is **Menkar**.

Almost overhead around 10 p.m. in mid-December is Andromeda's rescuer, **Perseus**, which includes the famous variable star **Algol** (usually second magnitude) and the slightly brighter **Mirfak** (beside which lies a fine collection of dimmer stars, best seen on very clear nights). Perseus basically consists of two branches of stars, which some people connect in his "helmet." Midway between his top and Cassiopeia, high in the north, you will find the fuzzy glow which is actually the double cluster of Perseus, two distant but mighty side-by-side star clusters.

The longer branch of Perseus leads south to a closer cluster, the prettiest of all in the heavens, the **Pleiades** or seven sisters. Most people have noticed this unique little grouping of gems and some have confused it with the Little Dipper (which is much larger and less conspicuous) because of its own tiny bowl-and-handle shape. It is only easy to see six stars there with the naked eye if your skies are not fairly dark, though the bigger problem in seeing many of them is often the fact that the Pleiades are so close together. In clear country skies, it is sometimes possible to identify a dozen or more if you know exactly where to look for them. Probably no sight in the heavens is as delicate and lovely as the floating Pleiades twinkling together like a little handful of lively jewels.

A five minute exposure on Ektachrome 200 push processed to E.I. 400 produced this striking image of an aurora against the stars of Pegasus and Andromeda. The camera was a Pentax ESII camera with a 24 mm lens at f/3.5. Photo by Brian Tkachyk.

The Pleiades are located in the shoulder of **Taurus** (the bull), but the prominent head is somewhat farther east and is one of the leaders of the brilliant winter constellations. The face of the bull is outlined by a "V" of stars which is made up of orange **Aldebaran** and our nearest star cluster, the **Hyades** (which are a bit brighter — on the whole — than the Pleiades, but far more scattered). The bull's head is completed by two stars which roughly extend the arms of the "V," forming horns for Taurus. The northern of these two, **El Nath**, helps compose the large pentagon of **Auriga** (the charioteer). The Crab Nebula is near the southern horn-tip, but it is not visible to the naked eye. Since Auriga is very northerly, it has been rising early for several months now, with its yellow star **Capella**, second brightest of winter, leading the way.

The constellation which adds the

most to the glory of the rising winter host needs little introduction: his belt of three aligned stars is set between two first magnitude giants. He is **Orion** the hunter and to the left of his belt as he rises is red **Betelgeuse**, while to the right is blue **Rigel**. Two more bright stars complete, with Rigel and Betelgeuse, the hunter's knees and shoulders. Watch him as he rises. No sight in astronomy is more awesome than Orion looming gigantic on our eastern horizon.

To the north of the hunter, **Gemini** the twins (source of the month's best meteors) rises with its two almost-twin stars, **Pollux** (slightly brighter) and **Castor**, and under Gemini is rising **Procyon**, the *lucida* (brightest star) of **Canis Minor**, the little dog. But best of all of these still-coming winter splendors is the star which lies at the end of a path extended east directly down the line of Orion's belt: **Sirius**, the blaze of Canis Major (Orion's big dog) and brightest star in the sky. Now is a perfect time to watch Sirius twinkling at its most vigorous (because it's low) — not only quavering, but having its blue-white glitter broken into piercing rays of all colors.

skylore

Even Orion and Ursa Major have probably not inspired more legends than the Pleiades. It is difficult to find a culture which has not taken note of this curious little group and woven around it some tale of high imagination.

The Pleiades of Greek mythology were the seven daughters of Pleione and Atlas, the giant who upheld the heavens on his shoulders. The parents now have their own stars, forming the handle of the star cluster's dipper shape. The best-known explanation of how the Pleiades and their mother reached the sky says that they were pursued by the amorous Orion who would have overtaken them if Zeus had not listened to their entreaties and changed them into doves who then flew to the stars. Later, Orion himself (along with his two dogs) was placed in the heavens, where he continues to follow, but never quite catch them as they all journey across the night sky.

Another famous story among the ancient Greeks was the Lost Pleiad: "The Sister Stars that once were seven/Mourn for their missing mate in Heaven." The strange thing is that this same idea also appears in the lore of the Mongols, Japanese, Australian aborigines, people of the Gold Coast of Africa, and many different American Indian tribes (who told different stories). The Dyaks and Malays of Borneo have a similar legend for they say that the Pleiades are six chicks protected by a mother hen who is always invisible.

The Pleiades. Photo by David Healy.

The Mongols' story is particularly interesting since according to it we can still see the missing star, because it is our Alcor, the companion of Mizar in the Big Dipper's handle: the seven great stars of Ursa Major were robbers and they kidnapped one of the seven sisters and took her north so that she is now called Huitung Ot (Cold Star). There are different opinions as to which of the Greek sisters was lost (some say Electra's face was dimmed in grief at the fall of Troy, which had been founded by her son).

The fascinating question is whether all these myths of the missing star could possibly have spread from one initial tale or whether there is a physical explanation in the actual fading of one of the stars. The former alternative seems extremely unlikely, but some commentators have suggested that the seventh sister or star was added to the prominent six because seven has been a mystical number in many cultures since earliest history: or, that the seventh Pleiad is lost only because it is seen by careful observers with good skies, but not by more casual viewers.

If any of the major Pleiades has really dimmed in historic times, it is most likely to have been mother Pleione, which has been known to be somewhat variable in the past few centuries.

Among the many enchanting American Indian legends of the Pleiades is one of particularly current interest. The Kiowa Indians tell of seven maidens who were chased by huge bears and sought safety on the top of the peak we now call Devil's Tower. The marks of the bears' claws can still be seen as weird striations on the tower's sides, but the Great Spirit saved the maids by lifting them to the heavens. Devil's Tower made a famous recent appearance in the movie *Close Encounters of the Third Kind*, and one must wonder if Stephen Spielberg knew that his fortunate characters were not the first to take off for the stars from this site!

From the other side of the world comes one of the most imaginative tales of Pleiades lore. According to the Hervey Tonga Islanders, the Pleiades were once a single star which outshined all others, flaming as brightly as a half moon (about as bright as the great Lupus Supernova of 1006 — is this tale a memory of that event, or another supernova?).

The god Tane overheard the Pleiad-star boasting of its beauty and enlisted the aid of Mere (Sirius) and Aumea (Aldebaran) to attack it. The three chased the star, which hid under the Milky Way until Mere raced to that stream's source and diverted the flow. But the great star rushed off and seemed certain to outrun his opponents when Tane suddenly grabbed Aumea and hurled him with such force that Aumea smashed into the great star and broke it into six pieces. Tane was satisfied, Mere became the brightest star, and the six pieces forlornly returned to their original place. But it is said that the six, which are now called Tauno, still sometimes gaze down into still waters to admire their beautiful reflection.

We now know that the combined light of the Pleiades is about equal to that of Regulus in Leo (somewhat fainter than Aldebaran), but the effect of the cluster's manifold brightness is greater, and we can only agree with Tauno that the six — or seven — are beautiful.

equipment
atlas

keeping warm while stargazing

by
Art Huffman

With the onset of the cold weather, many amateurs pack their telescopes away for the duration. How hardy are you? Are you getting out on those frosty winter nights when Orion walks high in the sky? Although summer skies offer the richest part of the Milky Way, winter nights have brighter stars and more prominent constellations. In addition, many areas have more clear nights during the colder months. And, if you live on the West Coast, knowing how to dress warmly can be most valuable for a summer night high in the mountains.

I teach observational astronomy. One of the most difficult points to get across to students is how cold it's going to be when they're stargazing outside at night. And, after the students have frozen a couple of times, it seems equally difficult to convince them that they can be warm while observing.

Stargazing is the coldest thing you will ever do. Don't say, "Oh, I've been skiing at 30 below. I can take it!" Stargazing is colder. Remember, you are going to be motionless most of the time, losing heat by radiation to the dark night sky, and possibly exposed to a cold wind. If you are active skiing or hiking in the winter, you may generate 2000 to 3000 watts of heat in your muscles. Standing still, you are reduced to near basal metabolism rate: about 100 watts. The daytime Sun may add 500 to 1000 watts to your body, and even the clouds hold the heat in. But, on a clear night, your body temperature is higher than that of a sky only a few degrees above absolute zero. So you lose heat by radiation.

Heat is generated in your muscles and circulated throughout your body by your blood. Heat lost through your clothing means the air next to your skin gets cold. Heat loss then occurs through the skin. As your body cools, your muscles begin shivering to produce more heat, and capillaries and other blood vessels begin shutting down the circulation to your skin and outer parts of your body to reduce the loss of heat. Too much heat loss from the central parts of your body can be fatal: this is why people die of "exposure."

The problem of keeping warm, like any other physical problem, can be attacked by the scientific method. This was done by the U.S. armed forces during World War II and Korea. The key result of the studies was that the only effective insulator is "dead air space," tiny pockets of air held immobile by fibers of insulation. Thus, only the thickness of the insulation matters, the thicker the better. It doesn't matter what the insulation is — wool, foam, dacron, down, or even steel wool or snow.

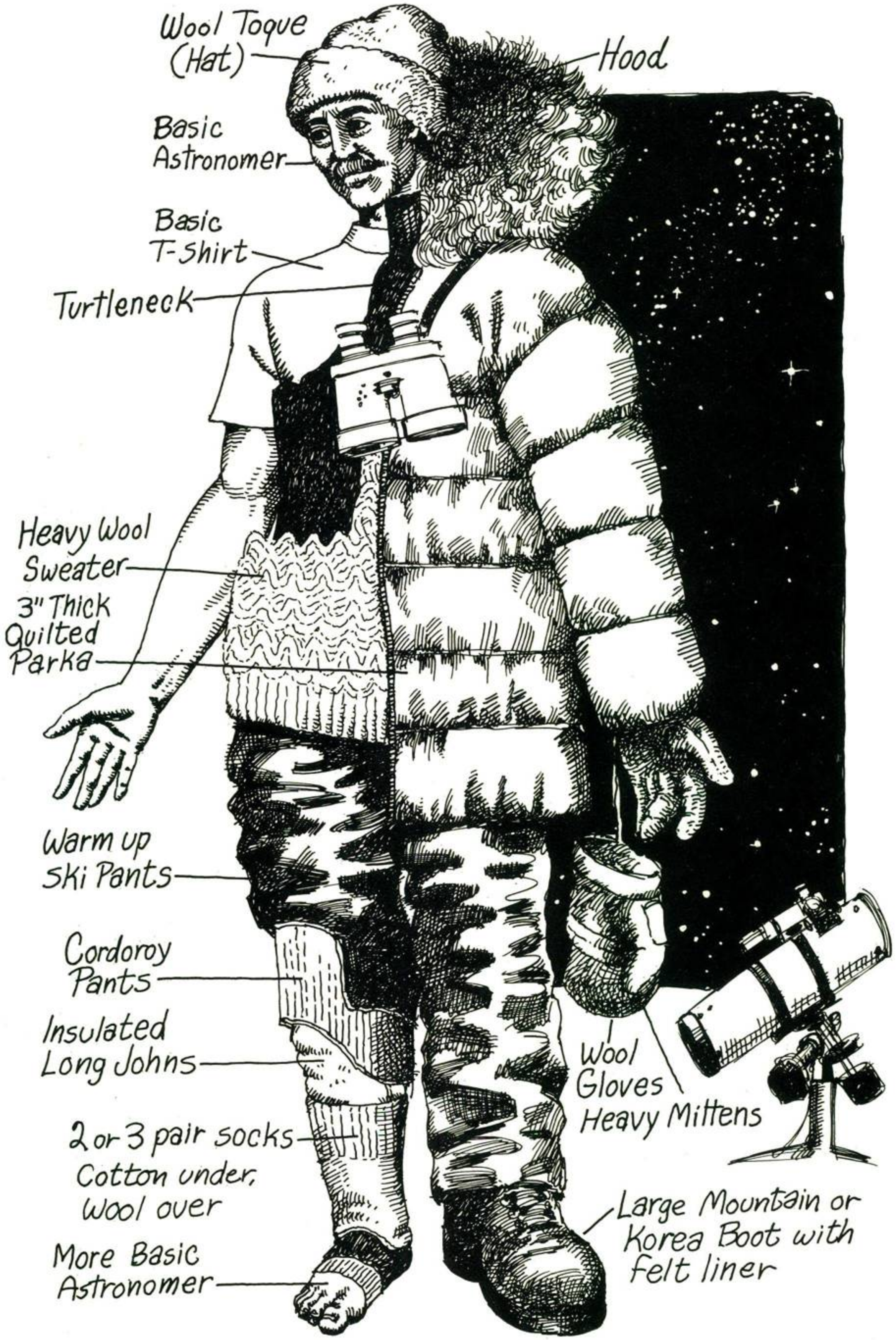
Do not be misled by advertisements claiming super insulating garments. Various materials may have their own desirable properties — cotton-lined insides feel more comfortable; wool is warm even when wet; "space" blankets reflect body heat back in; down is the lightest insulator for a given thickness — but it's the thickness that keeps you warm.

One especially desirable property if you are partly active is that the material of the garment "breathes." This means it is *not* waterproof. When you are momentarily active and warm, you will perspire. Later, when you're not active, your sweat may condense on the inside of a waterproof garment next to your skin and make you cold. Materials that breathe allow water to escape, and you stay dry and warm.

Ski clothing, often used for stargazing, seems to be designed to look good, form-fit, and to allow freedom of movement. It's not good for stargazing. In stargazing you are less active. Good looks don't count in the dark, and being warm is more important than freedom of movement. Ski warm-up clothing, or

All art
by Bruce Bond.

CROSS SECTIONAL VIEW OF THE PROPERLY ATTIRED OBSERVATIONAL ASTRONOMER


Wool Toque (Hat)
Hood
Basic Astronomer
Basic T-Shirt
Turtleneck
Heavy Wool Sweater
3" Thick Quilted Parka
Warm up Ski Pants
Cordoroy Pants
Insulated Long Johns
2 or 3 pair socks Cotton under, Wool over
More Basic Astronomer
Wool Gloves
Heavy Mittens
Large Mountain or Korea Boot with felt liner

any thick insulating garment, is better. Your goal, even for a cool summer night, is getting one to two inches of fluffy thickness around your torso. A down parka is ideal in terms of lightness, thickness, and breathability, but several wool sweaters and a thick parka of synthetic fiber are nearly as good. Layers of clothing must fit loosely so as not to restrict blood circulation to your arms and to retain lots of "dead air space." Long underwear, both top and bottom, is a very cheap investment for the greater warmth it provides.

Head

Your body is smarter than you are; it considers your head and vital chest organs to be the most important parts of you. It will try to maintain their temperature at all costs. If your uncovered head is causing you to lose heat faster than your body is producing it, your body will begin shutting down the circulation to your fingers and toes, and then your arms and legs. Your outer extremities will become frostbitten to maintain your brain at proper operating temperature. Moral: To keep your toes warm, cover your head.

Hands

Thick mittens are warmest, but gloves may be useful for adjusting telescopes and cameras. Wear heavy mittens over light cotton gloves, especially if the temperatures are extreme. Damp skin can freeze (instantly) to metal parts when the temperature is 10° or below — the gloves protect you and keep you warmer, too.

Feet

Feet are the biggest problem for most people. Why? Poor footwear. The best footwear is the double boot or Korea boot of the winter mountaineer. It won't do any good to stuff more socks into your normal shoes; they will just cut off the circulation and make the problem worse. You need a larger size boot, with several layers of loose wool socks. If you're lucky, you may still be able to get Korea boots from an army surplus store at a reasonable price, but one cheap solution is large rubber golashes with several pairs of wool socks. And be sure your head is covered.

Women

Scientific studies show that women can withstand several degrees colder temperatures than men, and trained Japanese diving girls get colder still without shivering, but it is my experience that it is usually the women who are standing around shivering in night observation sessions. Perhaps in our society women dress more for looks than warmth, or perhaps it's just that men endure the pain stoically. Women: you simply must pack on plenty of loose fluffy insulation. Try borrowing a parka several sizes too large from a larger friend and wear it over your normal warm clothing.

THE PROPERLY TIRED OBSERVATIONAL ASTRONOMER

STAR BUNNY
SNO BUNNY

What to Wear

When "suited up," check that your clothes are not binding, particularly that they don't restrict blood circulation under your arms, and that your toes are free to wiggle. You should have two inches of insulation thickness around your torso, one inch on your legs, a wool stocking hat, and gloves or mittens.

If you are still cold when you go out with this much on, add more next time. No matter how cold-blooded you are, there is a thickness of insulation that will keep you warm.

Here is what I wear on a winter or mountain summer night:

Upper body:
- T-shirt
- Turtleneck
- Heavy wool sweater
- Winter expedition parka 3" thick with wolf ruff
- Wool gloves
- Wool toque

Lower body:
- Underwear
- Long underwear
- Heavy corduroy pants
- Ski warm-up overpants
- Cotton socks
- Heavy cotton socks
- Ragg wool socks
- Heavy mountain boots

Final Advice — To enjoy stargazing, you'll want to spend many hours out under the dark night sky in all seasons watching the constellations rise and set, and observing with binoculars and telescope. You won't enjoy it unless you are able to keep comfortably warm. Ordinary warm clothing is not enough! Your old hunting jacket or your fur-lined dress coat won't do it. Take extraordinary measures to dress warmly — and the cold won't faze you.

Art Huffman teaches astronomy at UCLA.

guiding

photography
in
astronomy

by
Robert Provin
and Brad Wallis

Taking fine-quality deep-sky astrophotos definitely has something of a mystique about it. With some folks it ranks right up there at the pinnacle of astronomical endeavor. Others, maybe those who've tried it once or twice and been disappointed at the results, can say little good about it or its practitioners. Between these two extremes fall most people — simultaneously envious of the results yet a little afraid of spending long, chilly, and possibly futile hours guiding a telescope.

The problem, of course, is that guiding looks like work. While there's no doubt that guiding does demand patience, a certain amount of skill, and some additional equipment, remember that *anything* you haven't yet mastered always looks more difficult than it turns out to be in the end. Let's explore just what it is you need to know and do, step by step. Maybe you'll agree it isn't all that hard after all!

Last month, in Equipment Atlas, Walter Hamler described the extra equipment you need to guide a telescope. To review briefly: your telescope is equatorially mounted and equipped with a guiding telescope (or off-axis guider) having an illuminated reticle eyepiece. In addition, you have a drive corrector and some method of making fine declination corrections.

When you have the necessary equipment, your first step involves setting up the telescope and aligning on the celestial pole.

Polar Alignment

Without precise polar alignment, even the most careful and accurate guiding will produce disappointing photos. Poor polar alignment necessitates constant corrections in declination, which will cause the stars in the photographic field to rotate around your guide star. You'll get a photo that looks like short exposure polar star trails. Here's how to align on the pole:

After you have roughly aimed the telescope's polar axis north, find a star 10° to 20° north of the celestial equator and near the meridian. Place it in the guiding reticle, and turn the right ascension drive on. Using a magnification equal to what you'd use for normal guiding, watch the star's direction of drift in declination while you keep the star centered in right ascension.

NGC-5907 is a dim, distant galaxy in Draco that we see edge-on.

If the star drifts to the north, the polar axis is too far west of the pole, while a southerly drift means the polar axis lies too far to the east. Gently nudge the polar axis in the appropriate direction. Re-center the star and continue this procedure until you whittle the drift down to one or two seconds of arc over a guiding period of 20 minutes. This aligns the mounting on the pole in azimuth.

Next, center another star in the reticle, also 10° to 20° north of the celestial equator but over near the east or west horizon, and do the same process. On the eastern horizon, a northerly drift indicates the polar axis is too high, while a drift to the south means it is too low. (The converse holds if your star is in the west.) Adjust the angle of the polar axis until it's correct. When you have finished these altitude adjustments, you may have to go back and "fine tune" the azimuth setting.

Trial-and-error is a little tedious, but this method will reduce declination drift to a minimum for most areas of the sky and you'll virtually eliminate field rotation.

Guiding Techniques

So much for preliminaries. Now find your object of interest in the main telescope and locate a star to guide on. In most cases, the cross hairs of the reticle should be aligned with right ascension and declination. This helps you orient yourself in the eyepiece field. On occasion, you'll discover that your only possible guide star is a very faint one. Then it's a good idea to rotate the cross hairs 45° — so the star can't drift undetected behind one of the cross hairs.

For the sake of practice, do a dry run: go through the motions of guiding for a few minutes before you actually start the exposure. This gives you time to learn how much correction will produce a given movement of the star image in the eyepiece — and in which direction. It's only a small investment in time, but it pays off greatly in better photos.

Some people feel that throwing the guide star slightly out of focus helps to create an image that is easier to guide on. There are two problems with this technique. First, by enlarging a star image, the overall image becomes fainter and more difficult to see, and second, the out-of-focus image produces parallax effects that can reduce guiding accuracy.

The dimmer image may not be much of a problem with a bright guide star, but the parallax effect is more serious. Why? To understand what happens, defocus a star image and move your head slightly while looking into the eyepiece. Since the out-of-focus star image and the cross hairs of the reticle lie at different distances from your eye, moving your head causes the star to move relative to the cross hairs. In practice, your natural eye movement would give rise to spurious image motions which you will then diligently "correct"! You'll do best to keep the guide star sharply focused.

How Much Magnification?

The amount of magnification required to track a long-exposure photograph properly is basically a function of the quality of the clock drive.

Magnifications as low as 2F (F = focal length in inches of the photographic lens) are possible when the mounting is properly polar aligned and the drive exhibits low amplitude periodic errors and little or no erratic ones. Most commercial drives don't meet this requirement; therefore higher guiding magnifications are necessary to nip incipient errors fast. With most photographic rigs, a guiding magnification of 5F to 8F is best. This gives you reaction time to compensate for the often large and rapid changes in drive rate that happen with low-cost drives.

Whatever your guiding magnification, tracking must be kept within certain tolerances if you want round star images on the film. Let's examine how tight the tolerances are.

Guiding Tolerances

Guiding tolerances depend primarily on the resolving power of the film and the focal length of the photographic lens. If you keep guiding accuracy within the limits that we'll work out in a minute, round star images will result — regardless of the final print scale.

It's unfortunate, but the resolving power of most films falls far short of the resolving capabilities of all but the smallest lenses. In most instances improving resolution in a photograph means increasing the image scale which in turn means going to a longer focal length lens. By way of example, the Kodak 103a films can produce an image as small as 20 microns — which, for example, with an 8-inch f/6 system translates to a resolution of 3.5 seconds of arc.

It isn't until you increase the focal length to 288 inches (or f/36) that the image scale will get big enough so that the 20 micron resolution achievable on film will equal the 0.6 second of arc visual resolution of an 8-inch objective. In any case, atmospheric turbulence normally limits photographic resolution to about one second of arc — even with big professional scopes.

Shuffling some numbers around, we find the resolving power in seconds of arc for any system using Kodak 103a or color film is closely approximated by:

$$165/F$$

where F = focal length in inches.

Given this value, it's a simple matter to establish tolerances at the guiding eyepiece that will define the allowable limits of error. Returning to the 8-inch

The Dumbbell Nebula (M-27) is a well-known planetary nebula in the Milky Way constellation of Vulpecula.

f/6 system described before, we know that the resolution is limited to approximately 3.5 seconds of arc. The problem now is to establish what 3.5 seconds of arc looks like in the guiding eyepiece. It so happens that a convenient measuring stick is readily available.

All stars viewed through a telescope appear to have small but discernable disks. Seeing conditions from night to night will vary the apparent size of this disk, but even on the best of nights there is an irreducible minimum size, which depends on the aperture of the instrument. This disk is called the diffraction, or Airy, disk. Its size (in seconds of arc) is given by:

11/A

where A = aperture in inches.

Also belonging to the Milky Way, but in the southern constellation Sagittarius, is the Lagoon Nebula, M-8.

However, since the Airy disk is not evenly illuminated but brighter at the center and dimmer toward the edges, the visual appearance of the disk is closer to:

5/A.

Thus the visual size of the Airy disk in a typical 3-inch refractor guidescope would be 5/3 = 1.7 seconds of arc.

The last step in this slightly roundabout process is to establish your guiding tolerance in terms of Airy-disk-diameters. To do this, divide the resolving power of the photographic system (165/F) by the size of the Airy disk in the guiding eyepiece (5/A).

Thus for an 8-inch f/6 reflector with a 3-inch guidescope, the guiding tolerance is 3.5/1.7 = 2. Therefore, for this particular system, you could let the guide star wander off the cross hairs by as much as one Airy disk diameter in any direction before you'd jeopardize the round star images.

Although this system is tried and true, variations are needed sometimes. While in theory the Airy disk is constant for a given aperture, the magnitude of the star should be taken into account. The formula 5/A gives the visual size of the Airy disk for a second or third magnitude star. Brighter and fainter stars will appear larger and smaller respectively.

Another factor is seeing. Usually the star's apparent disk is larger than the Airy disk due to atmospheric turbulence. Blurry stars are difficult to guide on and bad seeing will degrade the quality of your photographic images. If your guide star isn't cleanly defined and relatively motionless, you ought to wait for better seeing, even if it means packing up photography for the night.

The 20 micron resolution figure is substantially more coarse than many films will achieve, and so you might think that tighter tolerances are needed for fine-grain film. Yet this somewhat arbitrary figure does seem to be the practical minimum image size, nevertheless. Light scattering in the emulsion and mediocre seeing prevent you from getting much better resolution on a routine basis. And so in a practical sense, the tracking tolerances based for Kodak 103a films and color films also apply to the higher resolution emulsions such as Technical Pan film as well.

De-Bugging the Glitches

O.K., you've done all you can to assure good guiding and you're still getting poor results — what *is* it that's going wrong? Your problem may be telescope flexure.

Flexure results when some component of the system, optical or mechanical, main scope or guide scope, moves during the exposure. (Flexure isn't usually a problem with off-axis guiders.) As many as half of the "badly guided" astrophotos people throw away could probably be blamed on flexure — nor is it just the hobbyist who's picked on: professional observatories spend thousands of engineering dollars to eliminate it in their scopes.

Fortunately, flexure errors often leave a very definite signature on the negative. Sloppy guiding usually results in a straight-line trail or stars that are round with spikes protruding at various angles outward from the center. Flexure characteristically gives star images that are hook-shaped, trailed and knotted, or even double. Here's how to check:

Three galaxies: Both M-101 (at left) and M-81 (at top right) are open spirals seen either face-on or nearly so. By contrast, M-82 (bottom left), an irregular galaxy currently undergoing star formation, is probably presented edge-on to our view. These two and all other photos in this article were taken by the authors.

First, set your telescope up as if you were preparing for a regular night of photography, making sure of polar alignment. Select a 4th or 5th magnitude star and center it precisely both in the field of the photographic instrument and on the cross hairs of the guidescope. (This is important: the star must be centered to minimize any field rotation effects in case the polar alignment isn't perfect.)

Next, load your camera with a fine-grain black and white film and focus as accurately as possible. After double-checking that the star is still centered in the cross hairs, make a 10 second exposure. To reduce vibration, start and stop the exposure by blocking the end of the tube with a black cloth or piece of cardboard. It is very important to keep the star *precisely* centered during the entire 10 seconds and to avoid jiggling the scope while starting and stopping the exposure.

When finished, let the telescope track for an hour or two without guiding. Then re-center the star in the guiding eyepiece and make another 10 second exposure on the same frame. Then advance the film to the next frame. Repeat this whole procedure three or four times, aiming at various parts of the sky (flexure typically varies depending on the attitude of the scope). Once all of the exposures have been completed, remove the camera and process the film.

A system free of flexure will pass this test by exhibiting sharp, round star images on the film. But if the images are slightly trailed or doubled, then one or more components moved during the time the telescope was tracking unguided. Most telescopes will exhibit flexure to some degree, especially with exposures lasting two hours or more.

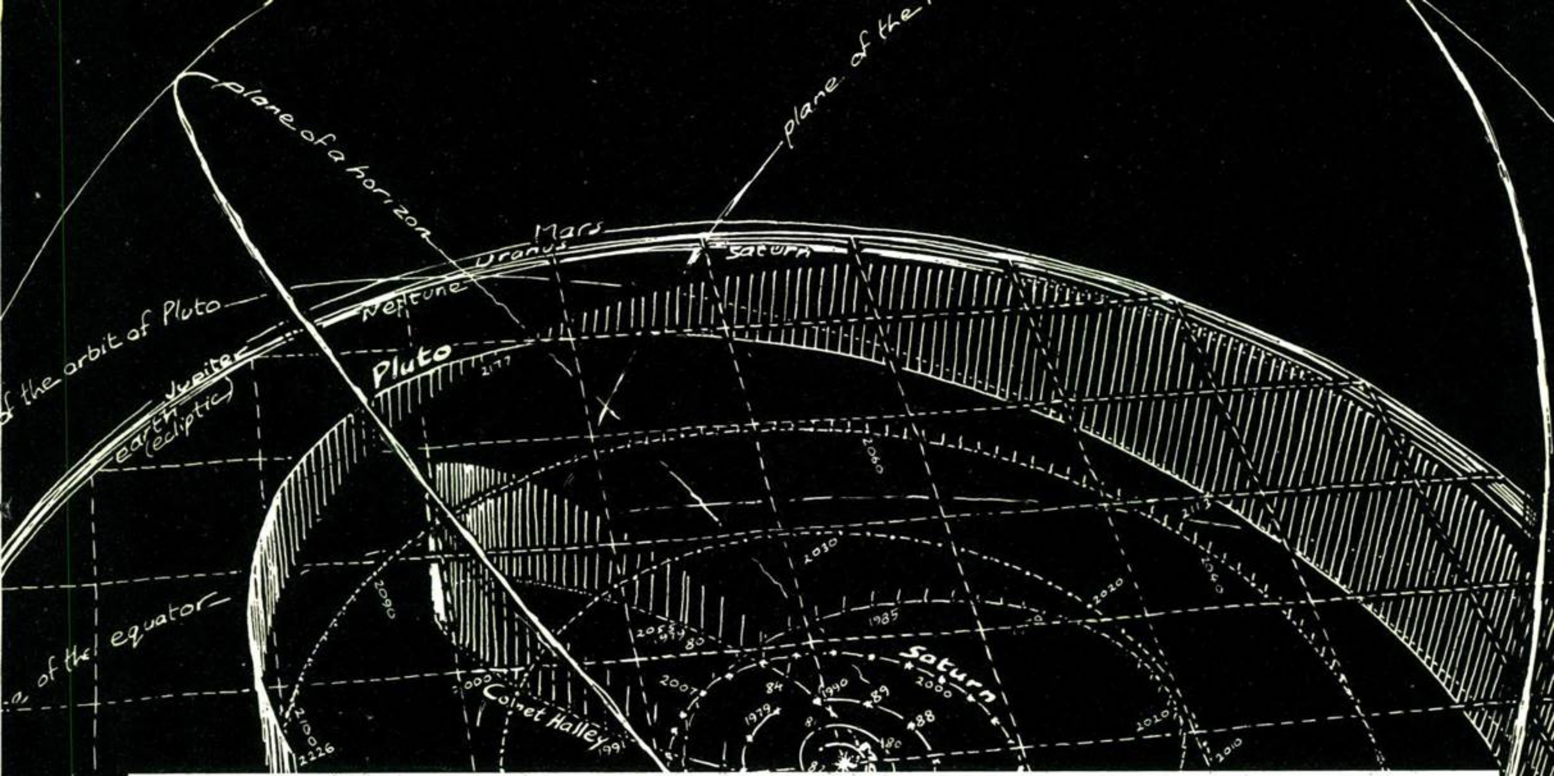
O.K., back to the trial-and-error: the components to check include optical supports (secondary and primary), guidescope mounts, focusers, and fiberglass tubes. Although all of these can contribute to flexure, secondary mounts which use cotton or similar materials for mirror support, and fiberglass tubes are probably the most frequent offenders.

A bead of silicon rubber aquarium cement applied behind it will grip a shakily-held diagonal mirror firmly but gently. This material, which sticks tightly to glass, can also be used to secure the primary mirror in its cell.

Go through your entire rig, item by item, tightening and adjusting — until repeated tests show that flexure has been eliminated. Every component of a photographic system must be mounted as rigidly as possible. Scrupulous guiding is wasted if the scope parts have a sloppy fit.

Skillful guiding can make the critical difference between the superb and the very good in deep-sky astrophotography, but no one should berate himself overly for less than impeccable results. You are not going to get perfection the first time out. And none of us will duplicate the work of a professional observatory, though practice and effort can give your photos a very fine polish.

Remember that while excellent guiding will produce finer resolution and fainter limiting magnitudes, more important is getting a feeling of satisfaction from your efforts, whatever their level!



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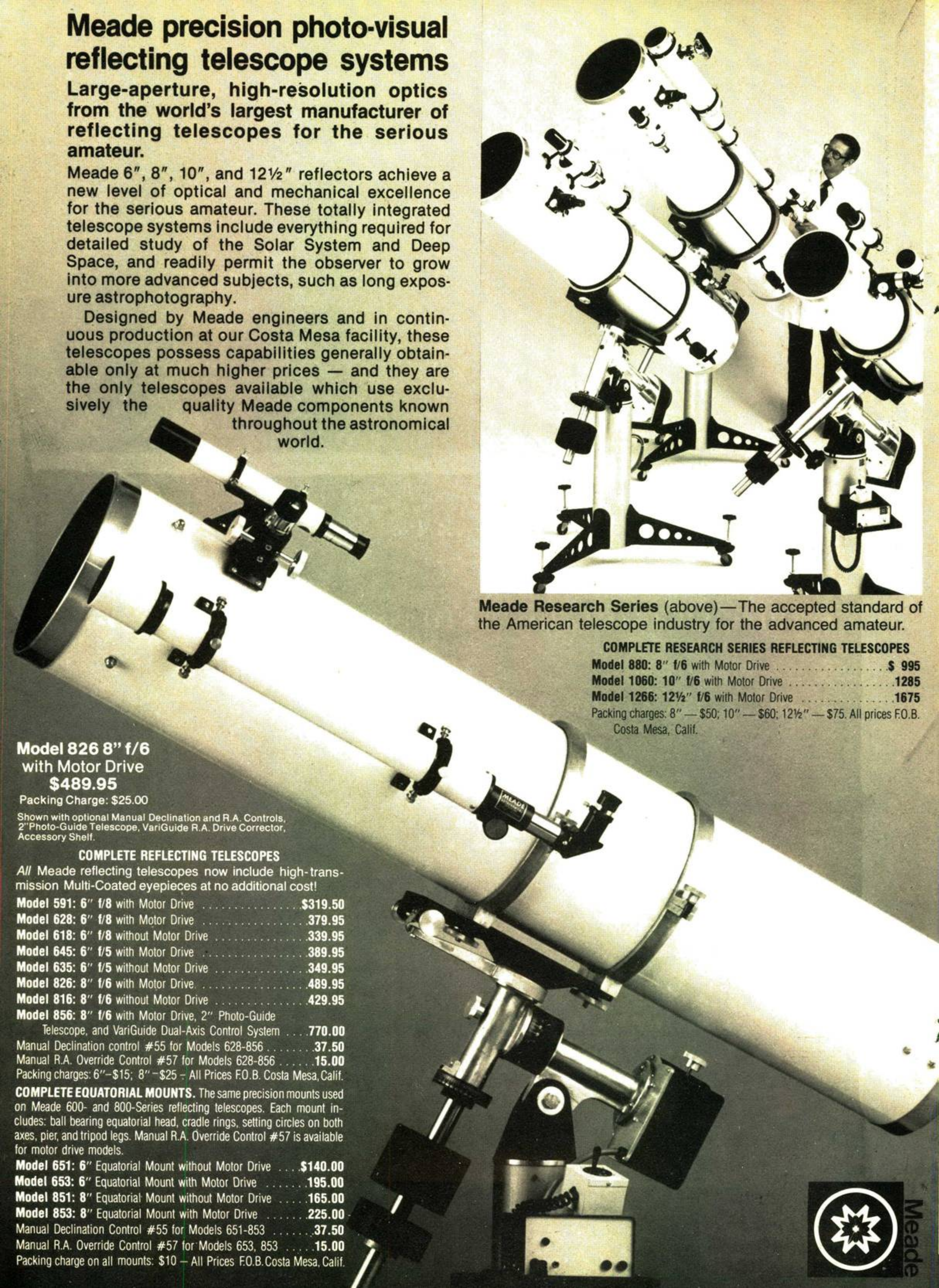

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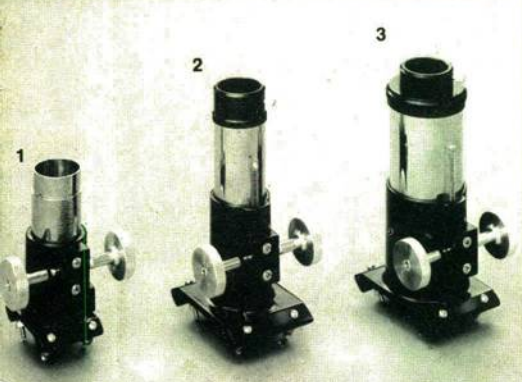

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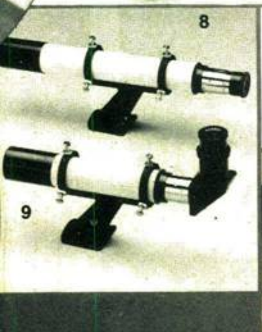

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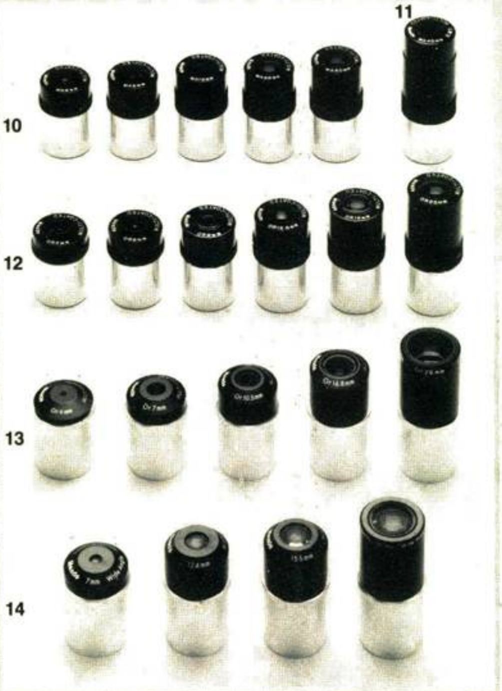

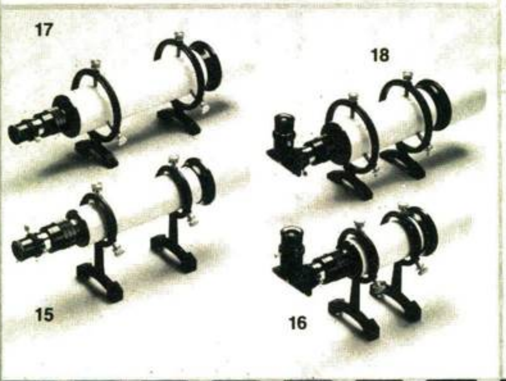

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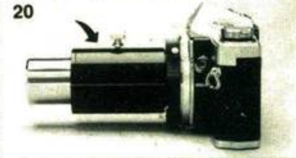
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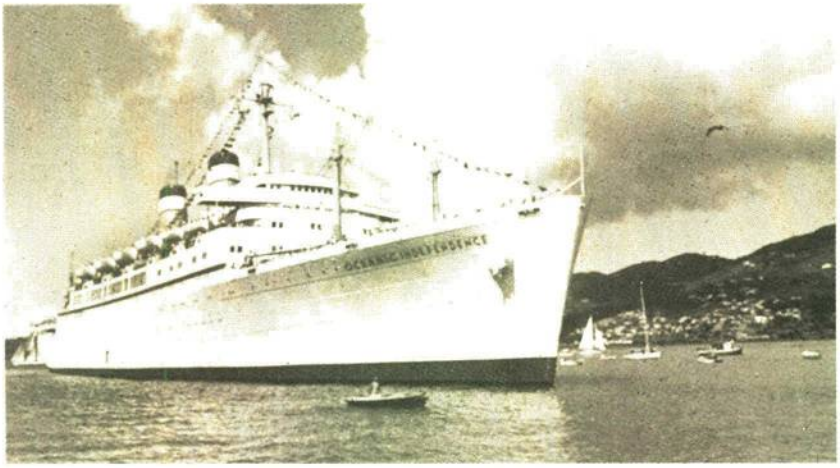

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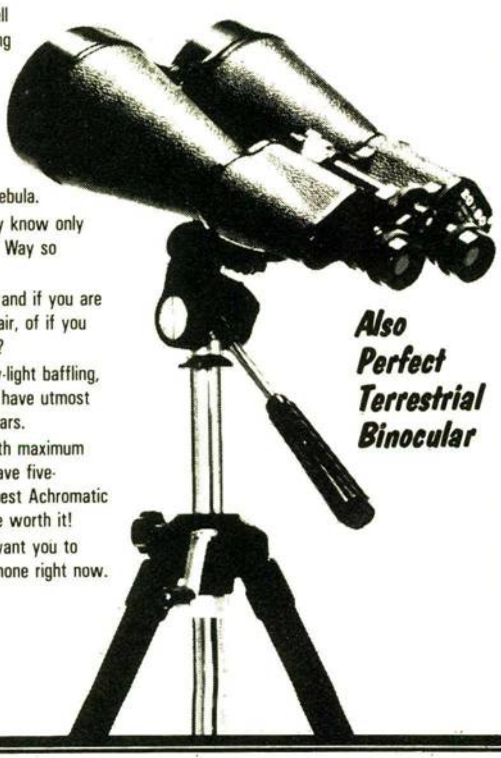

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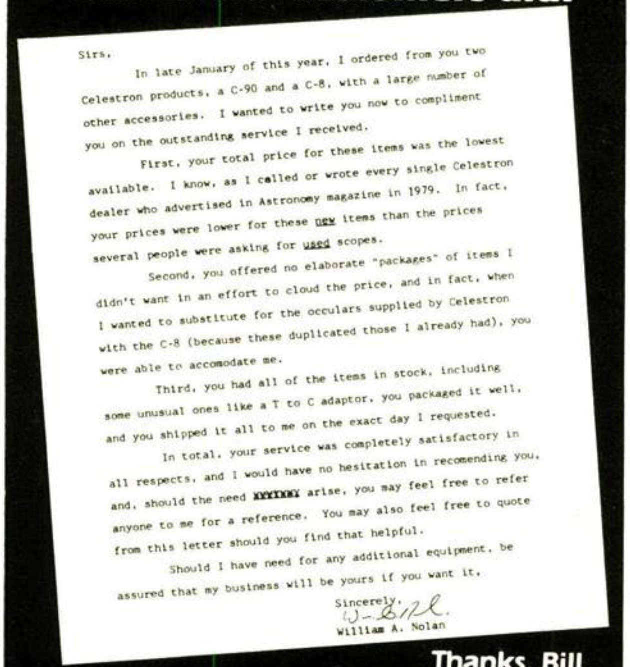

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the moon: ring mountains and walled plains

Amid the profusion of craters littering the Moon's surface, a few giants stand out clearly: Clavius, Schickard, Langrenus, and others. Smaller than the littlest of the dark-floored maria, their size places them above and apart from the common run of craters seen everywhere.

Previous generations of selenographers also saw them as different. Believing that most lunar features were formed by internal "geological" forces, they called these craters mountain rings, walled-plains, bulwark-plains, ring-plains, and the like.

We now know from the Apollo missions that even the biggest craters lie on the upper end of a continuum of impact features ranging from microscopic "zap pits" to basins like Mare Imbrium. Still the archaic descriptions linger, probably because their amiable terrestrial allusiveness satisfies telescope owners — who are often more in search of scenery than geological agents.

Looking on these expansive depressions ringed by lofty mountains provides a unique thrill for any moonwatcher. Apart from the immense maria, nothing else wraps up so much lunar territory in each formation. Their often convex floors curve to match the figure of the Moon itself. Their walls are usually high, yet many would lie beyond the horizon for a viewer standing at the crater's center. Lastly, they are among the most ancient of all lunar features.

The Young Moon

Let's start our exploration with a Moon just three days past New. At this phase, it's only a thin crescent — nearly featureless on your first look into the eyepiece. But along the southern part of the crescent, very near the limb, you'll soon make out an elongated depression. Being near the limb, its actual circular shape has naturally been very greatly foreshortened into a skinny ellipse. This is the 125-mile-diameter crater Humboldt. Despite its being over 15,000 feet deep, it appears very shallow — a characteristic common to many of the ring-plains. Look carefully at Humboldt tonight, but plan to come back to it a day after Full Moon, when the slanting evening light will bring out many hills and craterlets on its floor.

Quickly now, before our young Moon sets, scan toward the north along the crescent, and at about the same distance from the limb, you'll meet another depression almost as large as Humboldt — this is Gauss. 110 miles in diameter, the floor of Gauss lies 13,000 feet below the mountain tops surrounding it. It, too, will reveal its details right after Full Moon: there are three or four craterlets on the floor together with some central hillocks.

Gassendi

Thomas Dessert

Between Gauss and Humboldt lie several other slightly smaller ring-plains which will appear if you sweep slowly and carefully along the crescent — either now or just after Full Moon.

Let a day or two more pass until the Moon's age is around four days. By then some other large features will appear, most notably Mare Crisium and Mare Fecunditatis. At least six ring-plains along or near the terminator now call out for your attention: Endymion, Messala, Cleomedes, Langrenus, Vendelinus, and Petavius (taking them from north to south, respectively).

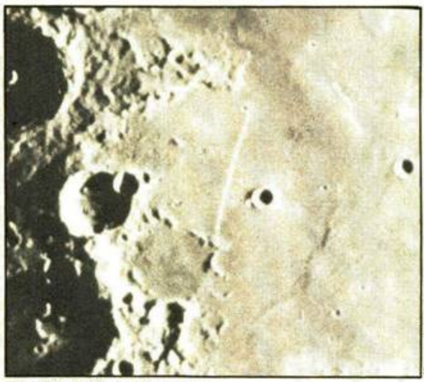
Endymion, 78 miles in diameter, has one of the smoothest floors of any lunar feature. Surrounded by 10,000 foot mountains (15,000 or more on the eastern side), the dark floor shows a convex surface; if seeing is good, you may spot a couple of craterlets in the northern part of the floor. Several observers claim to have seen changes in the brightness of the floor during the month, but this is probably just a contrast effect between the dark floor and the lighter hills around.

Messala, only a little smaller than Endymion at 77 miles' diameter, lies a short distance to the south. In Messala the rather low crater walls are battered and indistinct, being much chopped into by valleys. The walls are highest (reaching only about 4,000 feet) on the eastern side. The floor, too, is much broken up with hills and smaller craters. A chain of the latter runs north-south at the southern end of the floor and culminates in the rim-crater Messala B.

South of Messala and just to the north of Mare Crisium lies Cleomedes, a 78-mile-diameter ring. Cleomedes, like Messala, has partially ruined walls that are higher in the east — substantially so in this case, since the peaks in the west reach upward of 8,000 feet and hit 9,000 or more in the east. By contrast, the north and south ramparts are considerably lower and appear to merge into the surrounding landscape. The floor is moderately rough, having a few hills and a tiny triplet of craters at its center.

Skipping over Mare Crisium, we find three ring plains, Langrenus (82 miles in diameter), Vendelinus (91 miles), and Petavius (110 miles). Even at first glance, you'll notice things in common between the first and last, and two ways in which they differ from the other craters we've seen so far.

First, Langrenus and Petavius have distinct central peaks in place of the flat expanses and low, rambling hillocks we've seen until now. These peaks reach heights of 5,600 feet (Petavius) and 3,300 feet (Langrenus). And second, their walls (9,000 feet with Langrenus and 11,000 feet with Petavius) show several terraces on the inside, indicating that material has slumped at some point in the remote past. Against these differences, they too have flat floors — Petavius even has a large rille on the floor extending to the west of the central peak array.


Tom Harris

Thebit & Straight Wall

Vendelinus, situated about halfway between Langrenus and Petavius, has the familiar flat floor with craterlet or two, but there's no central peak and the outline of its rather low walls (about 5,000 feet) is much less sharply pronounced. Touching it to the northeast is the crater Lame.

Why should Langrenus and Petavius differ? No one can say for sure, but it may be that they formed late enough in the Moon's early history — after the uppermost layers of the lunar crust had cooled somewhat — to miss being extensively altered.

Into the Southern Highlands

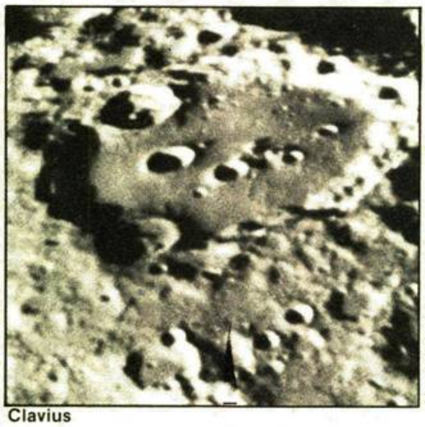
At 4.5 days after New Moon, a large, irregular, and much battered crater lies near the terminator in the southern highlands. This is the 118-mile ring named Janssen.

Containing few level areas (like most of its highland neighbors), Janssen has been much modified by cratering subsequent to its formation. The largest "intruder" is 48-mile-diameter Fabricius (whose wall adjoins that of 55-mile Metius on the outside). On the southwestern wall lies 21-mile Lockyer, and several smaller craters, hills and ridges spread out across the crater's bumpy floor. Janssen's age must be very great indeed for it to appear as dilapidated as it does.

A little past First Quarter, the advancing rays of the Sun pick out many additional interesting objects. Easily the most impressive of these is the giant ring-plain, Clavius. Long a rightful favorite among telescope owners, this 140-mile-diameter ring-plain is one of the largest craters on the entire earthside hemisphere. It's even so big you can see it with your naked eye! Look up and try to see a tiny dark indentation in the southern "horn" of the Moon when the tops of the walls of Clavius are sunlit and the crater floor is in shadow. Sharp vision will disclose it surprisingly easily.

In a telescope, of course, the view almost explodes with features. The immense wall contains two craters at the east end: Rutherfurd (south wall) and Porter (north wall). Each is about 30 miles in diameter and has terracing on the inside and hills on the floor. Extending north and west from Rutherfurd curves a chain of four smaller craters, Clavius D, C, N, and J, in a regular pattern that has led some observers to assume an internal (volcanic) origin for Rutherfurd and the chain members. Like so much about the Moon, no one can yet prove this one way or the other.

Clavius' walls rise to heights of 12,000 to 17,000 feet over the convex floor. You'll see places where many slumps have occurred, and in at least two places craters (besides Rutherfurd and Porter) have formed on the wall-tops. The floor itself is relatively smooth, but a field of craterlets exists between the aforementioned curving chain and the south rampart of the crater. In addition, the grazing light of sunrise and sunset will pick out some low ridges to the southwest of Porter.


Howard Zeh

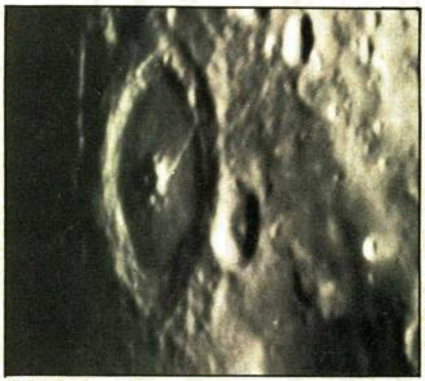
Clavius

We must push on now for other sights, but linger here as long as you want for it's difficult to exhaust the delights of this one crater.

North of Clavius and a little east, past the twin ring-plains of Longomontanus and Maginus (each worth a good look in themselves) and beyond the rayed crater Tycho, lies a ruined circular formation on the southeastern shore of Mare Nubium. Shown on some old maps as Hell-plain or Hoerbiger, the official name for this feature is Deslandres.

Despite being 145 miles across, Deslandres is easy to overlook because its battered and irregular outline is not very prominent. Lexell (39 miles diameter) and Ball (25 miles) craters break into its wall on the south, while 84-mile Walter dents it on the east, where a valley or notch in the wall seems to lead from one crater to the other at floor level. (Lexell's northern wall has also been breached, probably by the lavas that flowed out onto the floor.)

On the western part of Deslandres' floor lies the 20-mile-wide crater Hell. Here and there across the crater floor spread a short string of north-south craterlets, numerous bumps and hills, and a partially inundated crater, Hell B, near the remains of the northern wall.


E. Ken Owen

Petavius

Just like Janssen, Deslandres is obviously old, for at times it seems to exist more as a "clearing" among other craters than as one in its own right — its original circularity is little more than a rough memory.

Just north of here can be seen the traces of an even more ruined mountain ring: surrounding the famous Straight Wall lie its much altered remnants. Only the eastern rampart is left, extending north and south of Thebit crater. Long ago, the western side was engulfed by the basalts of Mare Nubium, though low Sun angles (at sunrise or set) will reveal the wrinkle ridges out in the mare where the wall lies, melted and buried.

Across the Western Maria

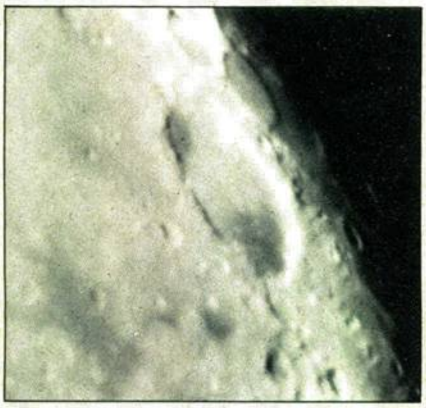
You'll see few new ring-plains as the line of sunrise creeps across the expanses of Mare Imbrium and eastern Oceanus Procellarum. But by the time the Sun has risen over Mare Humorum (lunar age: 11.5 days), a fine example is in view, Gassendi.

With Gassendi, we see the remains of a ring wall 68 miles across, much melted and breached on the mare side. The crater has a central peak complex, an intruder (Gassendi A) in its northern wall where the heights reach nearly 9,000 feet, and many rilles snaking across its floor.

It's uncanny, but anyone looking at Gassendi has a perfectly clear picture of what happened, almost instantly; the partly melted and inundated aspects tell the tale unmistakably. Sometime after the Mare Humorum impact gouged out the basin, a large meteor hit and formed Gassendi — which probably resembled Copernicus or Theophilus craters.

Time passed, and the basalts lying beneath the lunar surface crept up, perhaps along fault lines below the impact basins, to spill out and flood the basin and crater. As they did, the floor filled up and the walls of Gassendi weakened and diminished, especially where they bordered on the new-made mare. A few faults, the result of settlement perhaps, broke across the crater's infill material, and the picture was complete.

Between Mare Humorum and Oceanus Procellarum stretches a small "promontory" of highland: Gassendi is on the southern shore; Letronne, another smaller ring-plain, lies on the northern. Very little is left of the yawning pit Letronne must have been just after it formed. Today, all you see is a flat embayment of dark mare basalt within two curving 3,000 foot walls 74 miles apart. High telescopic power and a night of good seeing may reveal a tiny (3-mile-diameter) craterlet, Letronne B, nearly alone on the "floor" of the crater. Elsewhere, only a few bright spots marking the location of a hill or two, mar the nearly flawless perfection of this ruined feature.

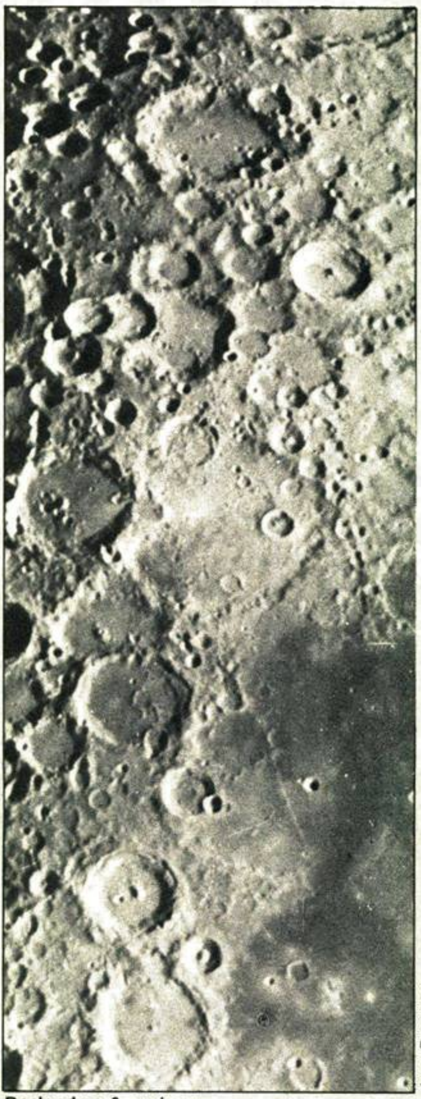

Danny Stagstetter

Schickard

A day or so later, take a look to the southeast of Mare Humorum where you'll see a very large, though greatly foreshortened, mountain ring: Schickard. Having walls only about 4,500 feet high, but a diameter of some 140 miles, Schickard is extremely shallow and would be relatively inconspicuous if its floor weren't so dark and featureless compared to its surroundings.

But not wholly featureless! Along the foot of the eastern rampart lie one craterlet, Schickard B, and a few tiny, low depressions. The southwestern part of the floor is more populated, having two craterlets and more depressions. But even here, good eyesight, moderately high power, and excellent seeing will be necessary to discern the features. More noticeable and conspicuous even in small instruments is the variation of brightness across the floor. Dark patches lie in the north and south, separated by a lighter colored band in the middle; the floor also appears convex.

A day before Full, look at the western limb of the Moon where you can catch sight of a complex of ring-plains almost on the edge of the visible hemisphere. The two most outstanding are 141-mile-diameter Grimaldi and 94-mile Riccioli. Grimaldi is very easy to spot, despite being on the limb, for it is very dark.

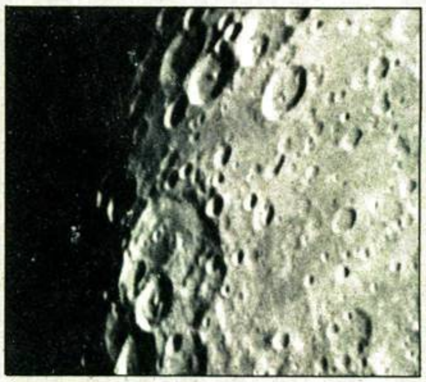

Jean Dragesco

Deslandres & environs

But your telescope will reveal a curious fact: Grimaldi's walls, though of medium height (4,000 feet or so), don't stand out very well. They seem lower than they really are, with the result that Grimaldi looks less like a normal crater than a sunken region smoothly flooded with dark basalt — or even a tiny isolated mare.

Riccioli, a short distance to the northwest, appears completely different. It too has dark material across its floor, but much less of it. The walls that circle the plain at an average height of 4,000 feet are very discontinuous — on the west they appear to merge into landscape around the crater, though this might be just a result of our low angle of view.

Riccioli's floor is studded with many low hills, craterlets, and rilles, but beyond detecting their existence, don't expect to see too much. The viewing conditions are just too difficult for modest-sized instruments.


John Allen

Janssen

To wind up this admittedly incomplete survey, let's sweep north from Grimaldi/Riccioli along the limb a short distance and take a look at Otto Struve. In form, this feature is a low oval ring of mountains and probably results from the merger of two neighboring craters into one.

Its walls are modest in height (approximately 4,000 feet) and the almost featureless floor inside is clearly convex — a fact that is very obvious just before Full Moon. There are a couple of craterlets in here on the eastern side, but very few. The lava flows that formed Oceanus Procellarum clearly invaded Struve and obliterated by melting or burial all previous features inside. The southern rampart of the ring-plain adjoining Struve on the east (Eddington) has also been destroyed: only the highest peaks of its former wall stick out above the mare surface.

The Moon swarms with far more ring mountains than we've noted here: some you'll have spotted near the ones we've discussed; others await your search. The hunting comes easiest along the western limb of the Moon, but don't overlook the more crowded southern highlands. Several lie near the south pole, and there's this very ancient, battered, and unnamed ring near Lindenau, Zagut, and Rabbi Levi....

— Robert Burnham

ASTRONOMY
IN FOCUS

Oberg in Defiance

Sir / In evaluating the comments of C. Leroy Ellenberger and L. M. Greenburg (Forum and In Focus, October 1980), readers should keep in mind the restricted intent of my original article (Forum, July 1980). In it, I examine *only* predictions regarding the physical nature of other planets and their atmospheres. It was not my intention (nor probably a fit subject for ASTRONOMY) to grapple with the validity of the full range of Velikovsky's theories.

My thesis remains unshaken by their rebuttals. They introduced issues remote from the subject under discussion, while avoiding the substantive issues I raised.

The massive amounts of argon and neon in the martian atmosphere are still not there. Velikovsky predicted them as consequences of his theories. This is a failure — regardless of who is or was editor of *Kronos*.

Moreover, the "killing radiation" of the Moon (not merely "anomalously high radiation") is not there, regardless of how the word "remanent" is spelled (in the manuscript received by ASTRONOMY it is spelled correctly).

And begging Mr. Ellenberger's pardon, radioactive dating *does* determine the age of rocks since last melting. Melting the rocks releases trapped argon atoms which make radioactive decay dating possible.

The citation of "Apollo-12 thermoluminescence data" (which they claim invalidates these radioactive dating techniques by indicating thermal disturbances within historical times) is simply fallacious. According to Dr. Robert M. Walker, the man who did the original studies, "The discussion of the thermoluminescence data by Velikovsky is completely wrong-headed...Any disturbance we might have reported would have been a physical disturbance resulting in the exposure of sub-surface material to solar heating. In fact, the thermoluminescence data prove that Velikovsky's contention — that the Moon surface was recently heated — is nonsense." These are the words of the principal investigator of the experiment, whose report is used by Velikovsky as support.

The Velikovsky prediction that the Moon's surface would be found to have been molten and to have been magnetized from the presence of some external magnetic field only a few thousand years ago, seems to have been abandoned by Juergens if he wrote (according to Ellenberger) that the magnetism could have been caused by lightning bolts hitting unmelted lunar surface rock. Without addressing the validity of that proposal, I submit that you cannot have it both ways.

Furthermore, neither hypothesis can account for the absence of any evidence for Velikovsky's postulated ocean of water covering the Moon.

Velikovsky said that Jupiter was cold, and it simply isn't. Unlike Venus, Jupiter gives off more heat than it receives from the Sun.

It also remains true that moonquakes are both tiny and rare. I quote from Elbert King's *Space Geology* (1976): "...The Moon is virtually aseismic compared with the Earth. If it were not for the extremely low seismic noise of the Moon, and good sensitivity of the landed seismometers, the Moon would appear to be very dead indeed." Compare this with Velikovsky's predictions and the subsequent rationalizations of his proponents.

The variety of scientific opinion regarding unexpected space discoveries provides a fertile garden for harvesting bits and pieces of authentic data which, when assembled, can appear to support the Velikovskian views. Such selection produces an incomplete and misleading picture. Viewed in the broad scope, Velikovsky's views fail, however convincing they may appear to people not familiar with the full spectrum of diversity within contemporary comparative planetology.

James Oberg
Dickinson, TX

Readers / Please note that Mr. Oberg's reply has been substantially shortened. He would have been perfectly pleased to "dismantle their arguments word-by-word and point-by-point."

Clearly one of the difficulties in testing the validity of Velikovsky's work is that all the predictions were qualitative rather than quantitative and phrased in lay terminology, hence the incessant haggling over wordings and phraseology. Nor, in reading the Velikovskian literature, is it easy to figure out what was and was not predicted, or for that matter, what most Velikovskians believe today.

Please note that the misspelling of "remanent" in James Oberg's original Forum article was a copy editing error. Mr. Oberg spelled "remanent" correctly in his original manuscript.

Fair Treatment

Sir / In reference to the Oberg/Velikovsky issue, ASTRONOMY magazine is to be commended for its fair treatment of both sides. I should like to add a point somewhat overlooked. At issue should not be Velikovsky's predictions, but how he arrived at them. It should be obvious to anyone who reads *Worlds in Collision* that it is based on magic like astrology and other forms of nonsense.

It seems consistent with logic that a science magazine such as ASTRONOMY would publish the article by Jim Oberg because it dealt with issues of science. If Velikovsky adherents were offended, it can only be the result of the inconsistencies of their belief system.

Michael R. Dennett
Vienna, VI

A Bright Meteor

Sir / On July 29 at 11:27 p.m. CST, my friends and I saw a bright blue-green meteor heading northeast. It lasted about 6 seconds before disappearing into the horizon. I would like to know if anyone else sighted this meteor.

Steven Belter
Pontiac, IL

The Moon Illusion

Sir / In reply to the dilemma of M. T. Marc of Lombard, Illinois, (ASTRONOMY, August 1980) about the Moon Illusion:

If you have a sextant, you can readily determine that whether the Moon is overhead or near the horizon, it still measures approximately 30 minutes of arc in diameter.

Or, try using the punched hole in a standard piece of notebook paper. To do this, catch a rising full moon — noting at what distance from your eye you have to hold the paper to just exactly circumscribe the Moon. Then just before going to bed, try it again. Even though the Moon is much higher now — and appears smaller — you will soon see that the same eye-to-hole distance will just fit the Moon's image.

Alternatively, observe the Moon near the horizon with a long cardboard tube, such as a mailing tube (the longer the better). Now by alternately blinking you will notice the Moon appearing larger with the nontube eye. A similar effect can be produced by extending your arm fully and then using the thumb and forefinger to "squish" the Moon. You will observe it becoming smaller. This phenomenon is brought about by association.

With the Moon overhead, devoid of anything for terrestrial comparison, it appears small; while near the horizon, any terrestrial item for comparison makes it appear larger.

As a final experiment on this comparison business, try this sometime. With a full moon near the horizon, stand with your back to the Moon — legs well apart. Then, bend over and observe the Moon between your legs. Now perspective is completely disturbed and with no familiar references, the Moon returns to its true apparent size. CAUTION: This is best done in relative privacy!

Charles B. Minnich
Orlando, FL

Space Litter?

Sir / Where I observe, at Deep Creek Lake in the mountains of western Maryland, the skies can be quite clear. It is not uncommon to see a magnitude fainter than the "book limits."

The passage of space litter across my field is quite common to the extent that I pity astrophotographers who must observe in the early evening before the Earth's shadow can hide it. At least once I have had two pieces of space junk cross my field while making an observation of a single object.

As an example, in September 1978, during just five nights, I made 36 variable star estimates representing about eight continuous hours at the telescope. During that time, three passages of litter occurred while I was using 9 x 39 binoculars (5½° field), 7 x 35 binoculars (11°), and a 6-inch at 118x (0.4° field).

I get quite riled about the senseless littering of our roads and beautiful woodlands; the world's space programs have rendered even the heavens no longer inviolate. But such is the price of "progress." I hope it has been worth it.

Gus E. Johnson
Swanton, MD

Ooops

In "21 Challenging Deep-Sky Objects" (September issue) Castor B lies 4 arc-seconds distant from its primary, not 4 arc-minutes.

behind the scenes

the giant ringed planet

Writing, as I am, in early October, still looking forward to the next few months of magnificent pictures and scientific discoveries, places you, me, and ASTRONOMY in an odd position. You will receive this copy of ASTRONOMY about two weeks after the Voyager 1 Saturn flyby on November 12. If the news media give any coverage at all, you will have already seen the best of the close-up pictures on TV, in the papers, and perhaps in weekly news magazines. Trying to provide you the best story we can five to six weeks before the encounter, this is frustrating for us, and doubly frustrating, I am sure, for you.

Despite the logistics of a monthly magazine, however, we still plan to bring you the best Saturn flyby coverage possible. Although we've earmarked the feature space at the front of the January ASTRONOMY for a generous spread of pictures and data from the encounter, it's going to be tough to get the story to you even for January. We've already worked out how we'll phone in my story and air freight the pictures back to Milwaukee on the 14th or 15th of November. That's just days after Encounter on the 12th, but in order to meet our press deadlines so we can get ASTRONOMY into the mail in time to beat the big Christmas mailing rush, we must do it that way. You can count on more coverage in the February issue — since we plan to publish every good picture that NASA and JPL release.

Meanwhile, we're proud to present this month's feature story "Of Transits and Timeballs." Once or twice each year we like to produce a story that's really different, a story that delves into an aspect of astronomy other than the astronomical "science" that we usually cover. Then, for sheer classical scientific detective work, you can't beat Mike Seeds' Stellar Frontiers on Algol. For the observers (now warmly dressed), we're presenting another part of our lunar series, and for the astrophotographers, more solid inside information on guiding, one topic our readers ask us many questions about. I hope you enjoy the issue!

Sincerely,

Richard Berry

Richard Berry

ASTRONOMY REVIEWS

Light and Its Uses
Readings from *Scientific American*
with introductions by Jearl Walker
147 pages, hardcover, $17.50;
paperback, $8.95
W. H. Freeman and Company (1980)

Ever since I was a small child, the Amateur Scientist column in *Scientific American* has drawn me back again more than anything else between its covers. I remember sitting in our attic on hot summer days reading the Amateur Scientist (and before it, the Amateur Astronomer) from the stacks of dusty old magazines, wondering at all the wonderful things that could be done, and absorbing something of C. L. Stong's outlook on the world.

Now many of those columns (some dating back to 1952) pertaining to light, my favorite topic, have been collected into a single volume. For the high school student looking for a prize-winning science fair project, or the adult "science nut" looking for a project of unusual interest, this book is invaluable. Subtitled "Making and Using Lasers, Holograms, Interferometers, and Instruments of Dispersion," this book is a gold mine of ideas, not just individual projects. If you want to know how to mount and adjust laser mirrors, for instance, you'll find several methods discussed in ample detail. All the devices are illustrated by Roger Hayward's crystal-clear exploded and cut-away drawings, masterpieces of clear graphic explanation.

The first section deals with lasers; many of the articles date back to the days when lasers were new. Would you like to build a helium-neon laser? It's not a job for a weekend hacker, but anyone dedicated to assembling the materials and learning to blow glass tubing, build a vacuum pump, and build a high-voltage power supply could do it. Once that was done, you'd want to move on to an argon-ion laser or a really high-power carbon dioxide laser (to melt bricks, etc.), or a nitrogen laser that emits 10 intense bursts of ultraviolet radiation with up to 100,000 watts of power.

Holography, by comparison, is tame stuff. A few mirrors, a dim beam of red laser light, and you could reconstruct the wavefront reflected from plastic chess pieces. Holograms work for radio, too, and Polaroid film turns out to be sensitive enough to record the constructive and destructive interference of microwaves.

Interferometers are esoteric. Much fun and a greatly increased understanding of light can stem from a device as simple as the Michelson interferometer: two mirrors, a beamsplitter, and some very stable mounts for them. I've played with these myself, counting the fringes between the sodium doublet, and even obtaining zero-path difference fringes from white light. They are sensitive, and you'll respect light a lot more from dabbling, even casually, with an instrument that can measure a millionth of an inch.

Instruments of dispersion cover spectroscopes, spectrographs, and spectrophotometers you can build in your basement. These powerfully analytical instruments allow you to perform an almost endless variety of experiments and measurements of the natural world. Of particular interest to astronomers are Walter Semerau's spectroheliograph and Gene Frazier's spectrohelioscope. (I dreamed for years of building Semerau's instrument, but never actually did.) Neither instrument is particularly inexpensive or simple to build, but either can offer rewards and satisfactions which you can't get from commercially available equipment.

For the encouragement alone, this book is worth its price several times over.

Richard Berry.

Man's View of the Universe: a pictorial history
Gerald E. Tauber
352 pages, hardcover, $19.50
Crown Publishers (1979)

Seven hundred pictures and diagrams, all in black and white, are the most distinctive feature of this handsome, oversize volume. These combine with the book's extensive text to help it achieve its goal of serving "the general reader both as an introduction to the science of astronomy and as an examination of how it developed."

Gerald Tauber, a professor in the department of physics and astronomy at the University of Tel Aviv, has divided his book into nine chapters, the first four covering the development up to the time of Newton. The fifth chapter chronicles the history of gravitational theory from Newton through Einstein. The discoveries made since the 17th century concerning solar system objects as well as the improvements in telescopic design which contributed to these discoveries form the foci of his sixth chapter.

The next two chapters, wherein the presentation proceeds to the Milky Way and the galaxies beyond it, are especially noteworthy for their rich cosmological content. The last chapter, "Man and Space," traces on an international level the history of the space program. A bibliography and index complete the volume.

Among the less obvious strengths of the book are its inclusion of more physics than you might expect and its attention to many very recent advances in astronomy. The author has also expended much effort in securing relevant pictures, many rarely seen in comparable works, and in constructing helpful diagrams and tables. Tauber's combining of scientific with historical presentations is effectively done.

A weakness in this book is that it contains more historical errors than you would hope for in a volume which will surely be widely read. Some are small and will be easily corrected, e.g., Huggins' telescope (p. 202) was a reflector, and the Palomar Schmidt camera (p. 225) has an aperture of 48, not 148 inches. Other errors are problems of dating, e.g., Copernicus did not decline (p. 91) an invitation to the meeting on the Gregorian calendar; none was sent — the great astronomer having been dead for nearly four decades! Also the item described (p. 65) as a 16th century woodcut dates from the 19th century. The astronomical views of Heraclides (p. 48), Wright (p. 253), and Shapley (p. 257) are misdescribed and W. H. Pickering's discovery of the ninth satellite of Saturn is attributed to E. C. Pickering, his more prominent brother. As a last example, Tauber twice (pp. 94, 338) wrongly ascribes the burning of Bruno to his astronomical doctrines.

But all in all, this is an effectively written and magnificently illustrated blending of astronomy and its history. It will not only grace the coffee table of the amateur astronomer, but also supply many evenings of pleasurable reading. *Michael J. Crowe.*

Low Latitude Aeronomical Processes

A.P. Mitra, editor
306 pages, hardcover, $60
Pergamon Press (1980)

Aeronomy is the study of the upper atmosphere especially as it is affected by the interplanetary flux of particles and fields. There are many consequences of this interaction, ranging from the aurorae to the disruptions that happen to long-distance radio communications to more esoteric effects. This book is a technical compilation of conference papers on the subject of what goes on in the upper atmosphere at low (geomagnetic) latitudes.

Atmospheric Phenomena

David K. Lynch, editor
175 pages, hardcover, $15.95; paperback, $8.95
W.H. Freeman (1980)

Astronomy and sky-watching often go hand in hand: the average telescope owner usually becomes something of a good amateur meteorologist. Yet beyond the immediate, pressing questions (Will it be clear tonight?) lie a great many fascinating atmospheric phenomena. This anthology of 18 articles from *Scientific American* collects under one cover descriptions and explanations of all the commonly occurring sights and some of the rarer ones as well.

There's a six chapter introduction that sets out the "basic considerations": water, ice, snow crystals and their growth, hailstones, and fog. This is followed by 12 more on rainbows, mirages, the Green Flash, lightning (both ordinary and ball), thunder, noctilucent clouds, aurorae and airglow, the zodiacal light, and atmospheric halos.

Each article is clearly illustrated (in the familiar *Sci. Am.* manner) and includes a bibliography for delving deeper into the subject. There's also an index.

Life Beyond Earth

Gerald Feinberg & Robert Shapiro
464 pages, hardcover, $14.95; paperback, $7.95
William Morrow & Co. (1980)

Subtitled "the intelligent earthling's guide to life in the universe," *Life Beyond Earth* teams a theoretical physicist (Feinberg) with a biochemist to provide an interesting overview aimed at laypeople. This isn't a sweeping examination like the classic Shklovskii and Sagan book — they concentrated a good deal on intelligent life and provided a fulsome background of astronomy. But with such a perennialy popular subject, an up-to-date treatment (like this) is needed every few years.

Quest: an autobiography

Leopold Infeld
361 pages, hardcover, $14.95
Chelsea Pub. Co. (1980)

Leopold Infeld was a Polish physicist who collaborated with Einstein in the late 1930s. The first edition of *Quest* appeared in 1941; this book is a reprint of it — and contains an epilogue which carries Infeld's biography up to 1965 (he died in early 1968).

For anyone interested in the scientific history of the period — a time of incredible ferment in physics — this fine book provides an excellent personal view.

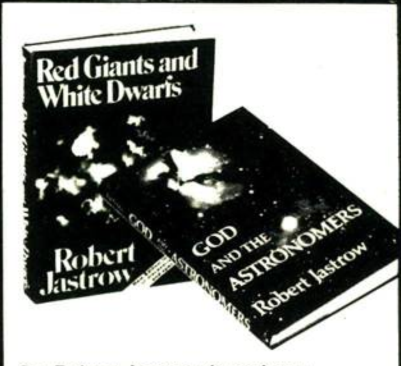
Handbook for Astronomical Societies 1980

Brian Jones, editor
78 pages, paperback, £1.90
Federation of Astronomical Societies (1980)
[order from the publisher: 28 High House Avenue, Bradford BD2 4ER, England]

Intended as a directory of U.K. societies, equipment suppliers, and local points of astronomical interest, this pamphlet would be of use to any astronomy buff visiting Great Britain.

THE ROMANCE OF SPACE

two great books by Robert Jastrow



Dr. Robert Jastrow is an internationally known astronomer and authority on life in the cosmos. He is the founder and director of NASA's Institute for Space Studies and also Professor of Astronomy at Columbia University and Professor of Earth Science at Dartmouth College. *The New York Times* says "Dr. Jastrow's scientific credentials are impeccable." HIS NEWEST BOOKS OFFER THE LATEST INFORMATION ON BLACK HOLES . . . UFOs . . . DYING STARS . . . LIFE ON MARS . . . THE MOONS OF JUPITER—AND THE MYSTERIES OF CREATION.

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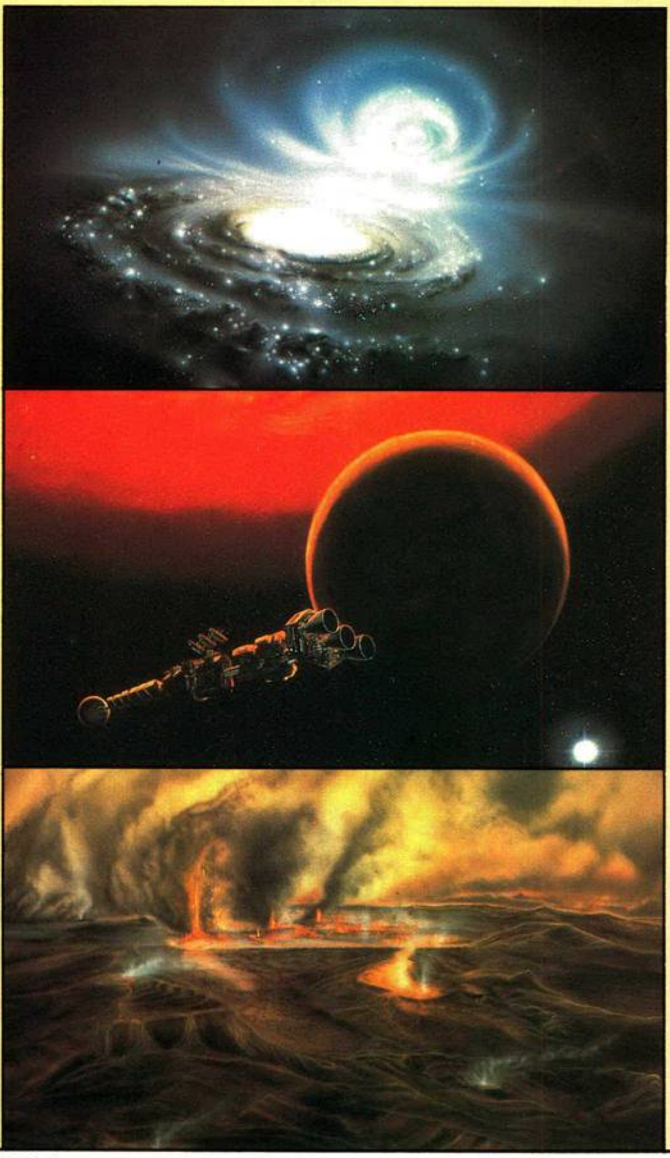

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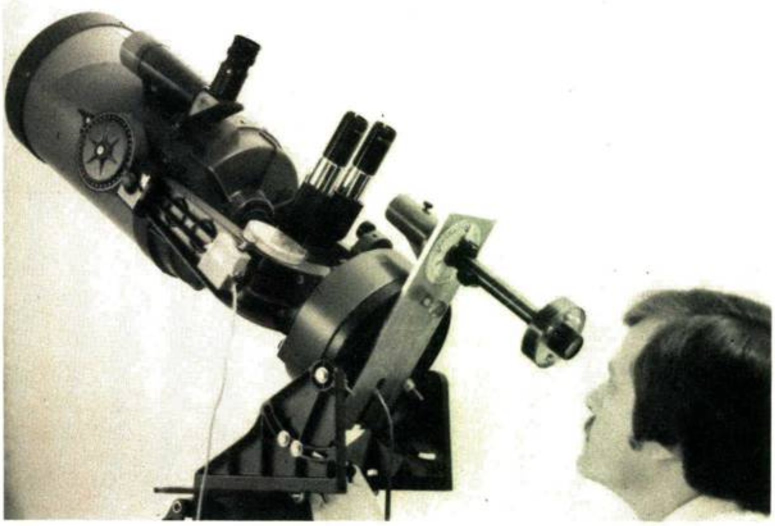

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New Evidence for Black Holes Found

Equally fascinating to scientists and laymen, a black hole is created when a massive star consumes its last reserve of nuclear fuel and then collapses inward upon itself. When this happens, its gravitational pull becomes so intense that nothing — neither light nor matter — can escape from its surface.

A black hole, postulated in Einstein's theory of general relativity, is therefore completely invisible and can never be observed directly, but new, strong evidence for their existence has been recently presented by a team of University of California astronomers. The evidence gathered by the UC astronomers consists of eliminating all other possibilities until a black hole remains as the sole surviving explanation.

The research, reported in the Sept. 1, 1980 issue of the *Astrophysical Journal*, was carried out at the UCLA astronomy department by Prof. Bruce Margon, Prof. Jonathan Katz and graduate student Allen W. Shafter, and by Richard J. Harms of the Center for Astrophysics and Space Science at UC San Diego.

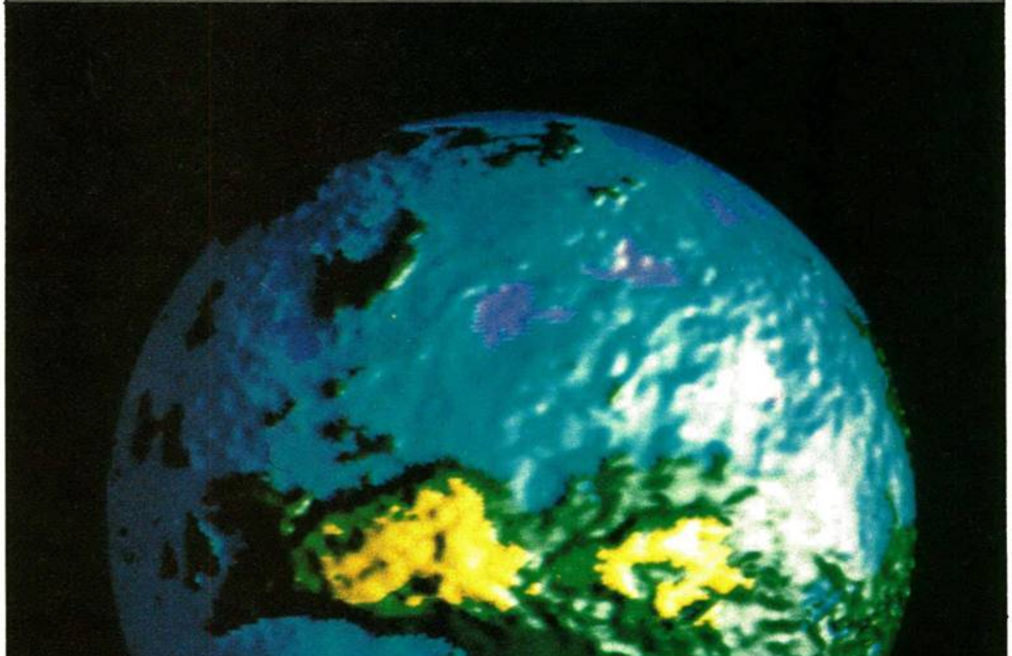
The researchers point out that a black hole can be detected indirectly if it is a member of a binary star system in which a pair of stars revolve around each other. According to physical theory, the tremendous gravitational pull of the black hole siphons off gases from its visible companion star, and the atoms collide as they are accelerated to high speeds and temperatures. This process creates X-rays, which can be an identifying signature of black holes.

One such powerful X-ray source was detected by astronomers about 15 years ago in the constellation Cygnus, some 10,000 light-years away. It was dubbed Cygnus X-1 and seemed to have the proper attributes for a black hole. A fairly bright star was found in its exact location, apparently its binary companion. The light spectrum of the visible star indicated that it revolved around the X-ray source with a period of 5.6 days.

The discovery split the astronomical community. Some believed that a black hole had been truly identified for the first time. Others, including Dr. John Bahcall at Princeton working with Yoram Avni of Israel's Weizmann Institute of Science, remained skeptical. They warned that Cygnus X-1 might simply be a very faint star, masked by the brightness of its luminous companion, much as a searchlight obscures an adjoining candle. But the photographic plates used in telescopes at the time were not sensitive enough to draw a clear separation between the bright and faint stellar spectra and thus resolve the controversy one way or the other.

"The skepticism was warranted," says Prof.

Venus Unveiled



This global representation of Venus stripped of its perpetual cloud cover was generated by a team of scientists at NASA's Jet Propulsion Laboratory in Pasadena, CA. The original data acquired by the NASA Ames Research Center Pioneer Venus Project have been reduced, transformed, filtered, and converted to spherical graphics by computer. Artificial illumination has been introduced to highlight surface relief. The colors are false, representing elevations relative to a standard radius. Lower elevations are shown in blue, medium in green, and high in yellow. The point of observation is directly over the equator at 90 degrees east longitude. The highland area which has been named Aphrodite is the most prominent feature in this view. NASA photo.

Margon, who recently joined the faculty of the University of Washington in Seattle. "Only last year another X-ray source in the constellation Scorpius was widely touted as a black hole, but subsequent measurements proved otherwise."

It took space technology to trigger another examination of Cygnus X-1. The new tool was the Digicon, an electronic light detector which can record light from very faint objects. It was developed at UC San Diego for the 1983 launch of the Space Telescope.

The UC astronomers attached the Digicon to the 120-inch telescope at the Lick Observatory to see if they could find, in Margon's words, "the candle next to the searchlight." They followed the visible companion star nightly in its 5.6-day orbit, looking for the telltale spectral lines that would identify Cygnus X-1 as a faint star and partner in a normal binary star system.

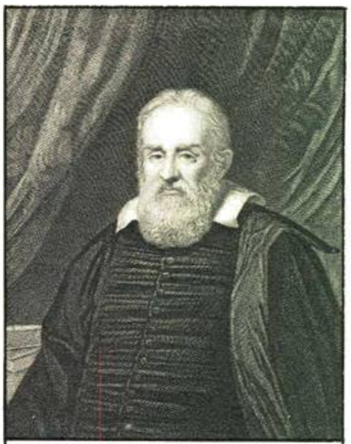
At the same time, theorists Jonathan Katz and Allen Shafter developed a new mathematical and computer technique to search for the faint signals from the second star.

After lengthy study, the team's conclusions were:

- No detectable light is being emitted from Cygnus-X-1, and it is not part of a normal binary star.
- The mass of Cygnus X-1 is thought to be about ten times the mass of the Sun. This rules out the possibility of a neutron star, which also emits X-rays but which would collapse of its own weight if larger than three times the Sun's mass.

The preponderant weight of evidence now points to the existence of a black hole, but the scientists are still cautious.

"Our findings do not represent absolute scientific proof for the black hole and there may not be any way of obtaining it," says Prof. Margon. "We are satisfied, however, that by putting Cygnus X-1 through these extremely sensitive tests we have greatly strengthened the case for the existence of at least one black hole in our Galaxy."



Galileo, the great astronomer who first turned the telescope on the heavens and made many significant discoveries, may have sighted Neptune as well.

Galileo Saw Neptune

Neptune, the solar system's outermost planet except for Pluto, is about 2,790,000,000 miles from the Sun. It is 15 times more massive than Earth, and orbits the Sun once every 165 years. Never visible to the naked eye, Neptune was only discovered in 1846. But according to two astronomers, it now appears that Galileo, the famous 17th century astronomer who chalked up many discoveries during his prolific career, was also the first person to observe Neptune — although he didn't know it was a planet.

Charles T. Kowal of the California Institute of Technology and Stillman Drake of the University of Toronto report that examinations of Galileo's observations show that the Italian astronomer actually saw Neptune twice — on December 28, 1612 and January 28, 1613 — some 234 years before the planet was officially "discovered."

While observing the planet Jupiter during two days in 1612 and 1613, Galileo recorded observations of "fixed stars" that happened to be near Jupiter. Painstaking research and studies of tables giving the computed positions of heavenly bodies during the 17th century, however, have convinced Kowal and Drake that Galileo actually was looking at Neptune.

"The indicated position of Galileo's 'fixed star,' the exact correspondence of the directions, and the absence of any bright stars in that area make us confident that Galileo actually saw Neptune on those nights," Kowal said.

Galileo's most important observation of Neptune was made on January 28, 1613. Neptune happened to be close to a bright star on that night, and Galileo made a drawing of both with a scale indicating their separation. He also noted that this separation was smaller than on the preceding night.

Textbooks record that Neptune was discovered on September 26, 1846, by a young astronomer in Berlin, Johann Gottfried Galle. Discovery of the planet, hailed as a great triumph of celestial mechanics, took a convoluted path.

In 1841 an undergraduate student named John Couch Adams at Cambridge University in England calculated than an unknown planet was disturbing the motion of Uranus. However, no one took his results seriously, and nobody bothered to look for the new planet at the predicted position. Instead, searches of large areas of the sky were undertaken. Meanwhile a French astronomer, Urbain Leverrier, became interested in the problem and, in 1845, came up with calculations indicating a position for the unknown planet. Leverrier's position was exactly the same as that predicted by Adams. French astronomers did not seem interested, so Leverrier wrote to the Berlin astronomer who found the planet in his first attempts.

Kowal said his studies lead him to believe there is a "strong possibility" that the ephemeris (astronomical data chart) of Neptune is in error by a significant amount. This would require a revision of the orbital elements of that planet, and suggests the existence of an unknown perturbation. The two researchers published details in the September 25 issue of *Nature*.

Pulsar Puzzles

A pulsar, according to most astronomers, is a rapidly spinning, extremely dense object formed by the collapse of a dying star. As a pulsar whirls on its axis, it emits sharp pulses of radio waves and, in some cases, light which flashes like a searchlight.

But a University of Texas astronomer says that that description of a pulsar "is not complete and may not be accurate at all."

"The pulsar is still a mystery in a very fundamental way," says Dr. Edward Nather, a UT Austin associate professor of astronomy. Dr. Nather and Dr. Brian Warner, a former associate professor at UT Austin and now a professor of astronomy at the University of Cape Town, South Africa, have received the Boyden Premium of the Franklin Institute for their experimental analysis of optical pulsar emissions.

After pulsars were discovered 13 years ago by two radio astronomers at Cambridge University, optical astronomers around the world focused their telescopes in the direction of these radio sources.

The attempt to see what was emitting such rapid radio signals met with "a spectacular lack of success," Dr. Nather recalls. "We found nothing but a blank field. After considerable discouragement, I made the general pronouncement they would never be seen

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optically."

Many astronomers, including Dr. Nather, quit looking. But a group at the University of Arizona didn't. One winter night in 1969 they trained their 36-inch reflecting telescope on a radio source in the center of the Crab Nebula and discovered that it was rapidly flashing in optical wavelengths. In keeping with astronomical custom, the Arizona astronomers immediately notified all other observatories by telegram.

Dr. Nather and Dr. Warner happened to be at the 82-inch telescope at UT Austin's McDonald Observatory in West Texas when the message arrived. The following night the two UT astronomers confirmed the discovery.

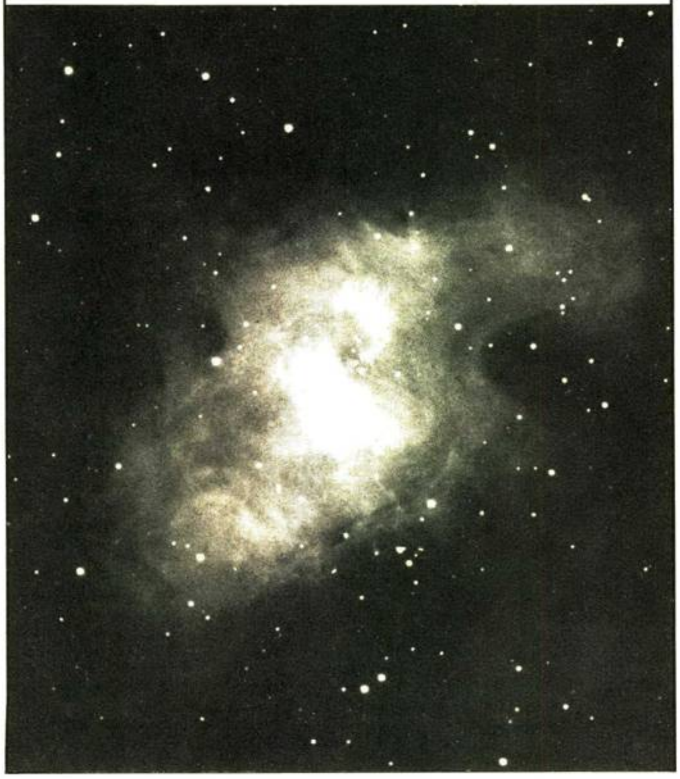
Fascinated by the object, Dr. Nather and Dr. Warner continued to study the emissions in considerable detail. They found the Crab Nebula pulsar fits the popular pulsar model in some respects but not in others.

One of their measurements showed the light from the pulsar to be highly polarized, meaning the light vibrates in a preferred direction. The pulsar's angle of polarization rotates through the flash of light almost 90 degrees, which fits the model, says Dr. Nather.

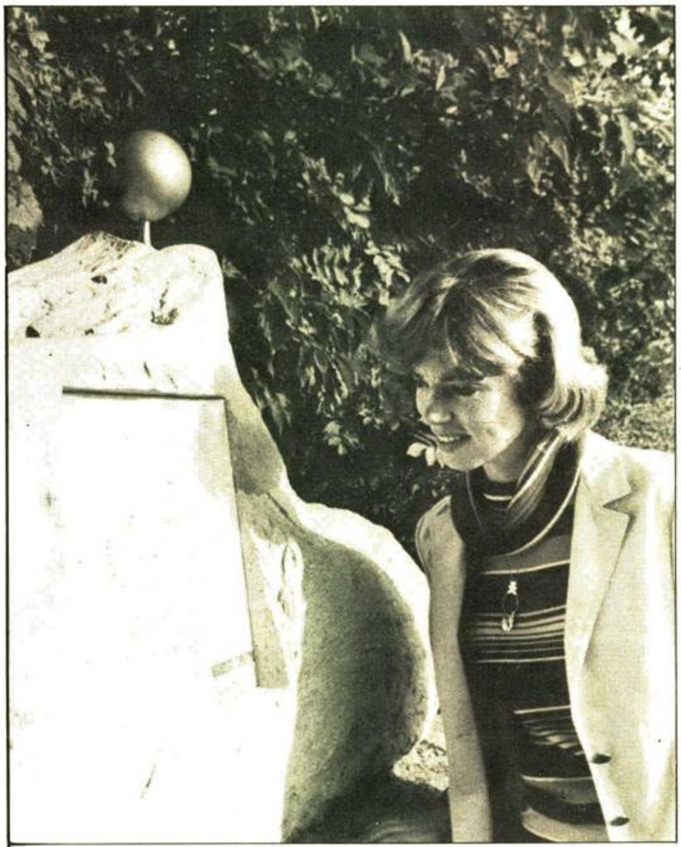
According to the current theory, though, the shape of the pulse should be symmetric. "But it doesn't look even close to it," says Dr. Nather. Instead, the pulse has a "weird, curious shape." He says he can describe the shape of the pulse mathematically but he doesn't know "what the mathematics means."

"Some very fundamental physics is going on that we don't understand," he says. "We've learned about all we can observationally, but we're too dumb to understand what it means."

Since Dr. Nather and Dr. Warner have revealed the mystery, what's needed now is a new theory to explain it all. But that will be work for a theoretician, according to Dr. Nather, not he himself. As an observational astronomer, he has a very special job to do: "I create problems; I don't solve them."



Observations of the pulsar lying at the center of the Crab Nebula (M-1) revealed that it was flashing rapidly at visual wavelengths as well as pulsing at radio wavelengths. But peculiarities in the shape of the light curve have been found. Lick Observatory photograph.



At the Planetenweg *(Path of the Planets) near Zurich, Switzerland, the planet Jupiter is represented by a steel ball in correct relative size to the scale of the entire solar system and the other bodies in it. Below the model is a map of the solar system and a table of data about Jupiter. Photo courtesy of Belinda B. Burum.*

Path of the Planets

It's not easy to say which planet has the best view. Of course Earth is pleasant, nestled in among all those trees. But Saturn, with its expansive view of forested hills, and Uranus, in the middle of a pasture, are hard to beat.

This is interplanetary travel at its greenest and most convenient — only 25 minutes by local train from downtown Zurich, Switzerland. Outer space has been brought down to Earth by the SKA-Planetenweg, or Path of the Planets, an installation that is the first of its kind on Earth.

It is the dream-made-true of Arnold von Rotz, a Zurich architect who has had a keen interest in astronomy ever since he was a child.

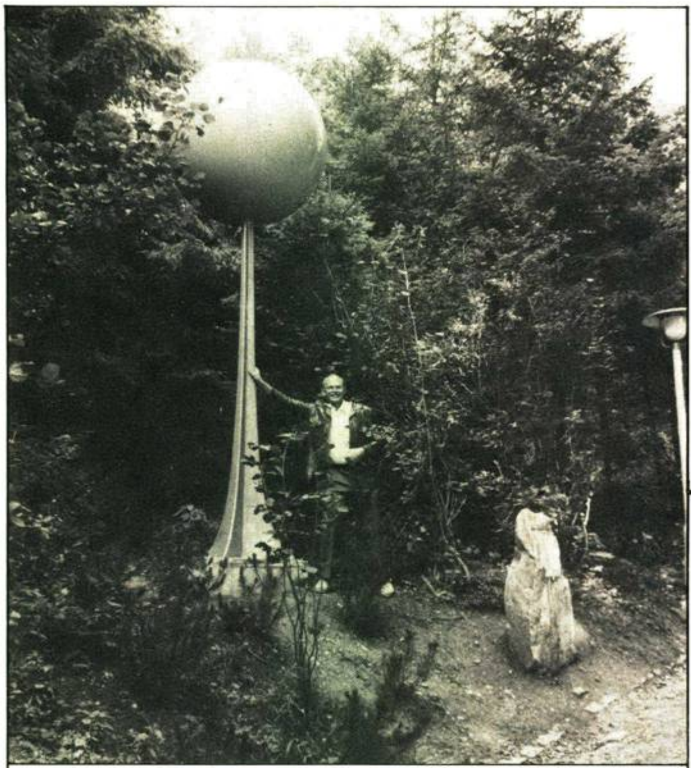
"It's hard for people to comprehend how big the whole universe is — the solar system, the Milky Way, the cosmos," explained von Rotz in an interview not long after the Planetenweg's first anniversary. "That's why I made the Planetenweg."

The Planetenweg is a path through the solar system that starts at a yellow polyester model of the Sun and progresses past scale models of all the planets. It capitalizes on a previously existing hiking trail along the top of a gentle group of mountains overlooking the Lake of Zurich to the east, and farmland, forests, and distant peaks to the south and west.

The Sun is stationed at the Uetliberg, a popular panorama point. From there the trail meanders through about four miles of fairly flat woods and farms dotted with a few restaurants, including one containing an exhibit on the solar system.

The scale of the models is precisely one to one billion, with one meter in distance equaling one million kilometers. According to von Rotz, this is the ideal size. Any larger, and the path would be too long; any smaller, and the planetoid Ceres, 1.1 millimeters in the model, would be too small to see.

As it is, the immensity of the solar system becomes



The Sun, the largest single object in the solar system, is mounted on a pylon at the beginning of the Path. A walk from here to Pluto takes about 2½ hours! Photo courtesy of Belinda B. Burum.

quite graphic, especially after one has walked for more than an hour without yet passing the halfway point. And reaching Pluto at its farthest orbital position from the Sun (three positions are shown) is an accomplishment worthy of celebration. It's a good 2½ to 3 hours' walk from the Sun!

The planets, made of steel, are mounted on rocks that were especially selected in quarries and from other sites by von Rotz and a sculptor working with him, to suit each model's shape, location, and size.

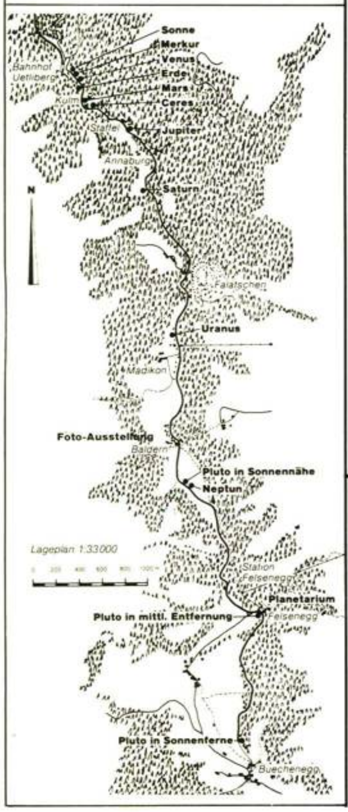
Large planets are mounted on top of the rocks; small planets float in acrylic plaques. On each rock is an aluminum tablet engraved with pertinent data about the particular planet — its size, number of moons, distance from the Sun, etc. — and a map of the solar system and the Planetenweg.

Also on each tablet is another important item: the insignia of Schweizerische Kreditanstalt or SKA, the bank which completely underwrote the project, its upkeep, and its publicity, including a 35-page booklet on the planets that is still sold at various magazine stands.

"We have no branches on Mars," the bank proclaims inside the brochure, "but you won't have to search far for us in Switzerland."

Von Rotz estimates that more than 100,000 visitors walked at least a part of the Planetenweg during its first year. He and fellow members of the Zurich Astronomical Society, project patrons, have given guided tours to groups ranging from city administrators and politicians to blind persons and school children.

The children, perhaps bolstered by science fiction movies and television shows (reruns of *Star Trek*, alias *Raumschiff Enterprise*, are popular here), seem to take the most active interest, according to von Rotz. They ask lots of questions, not only about the planets, but also about black holes, pulsars, and other popular cosmic wonders.



Interested queries have come from other astronomical groups in Europe. Von Rotz is pleased to report, however, that not only officially organized groups take a serious interest in the Planetenweg. One Sunday not too long ago he and his wife were out enjoying the fresh air and the planets when they came upon Saturn. There, to his delight, stood a group of about 50 adults, reading their booklets and carefully studying the planet and its steel rings. Nothing could have pleased him more.

Mammoths Done in by Dust?

It's become popular recently to blame biological catastrophes on extra-terrestrial agents. Walter and Louis Alvarez have said that the dinosaurs were killed off 65 million years ago by the side effects of a giant asteroid impact. John O'Keefe believes the sea-living radiolaria of 34 million years ago died off as a result of a temperature drop caused by an Earth-girdling ring of tektite-like particles.

Now it's the mammoths, who disappeared 11,000 years ago.

The eminent astronomer Fred Hoyle and Elizabeth Butler of the Department of Geology at Oxford University, think the elephantine creatures passed on *not* because of a sudden drop in temperature, but rather a sudden *rise*. And they think it was extraterrestrially caused.

In a letter in a recent issue of *The Moon and the Planets*, they suggest there are actually two different kinds of dust particles that could be deposited in Earth's atmosphere by an asteroid impact or a cometary close encounter. The first would be heat-reflective particles, which would rapidly reduce surface temperatures by reflecting back into space a portion of the Sun's rays.

The second kind would be heat-absorbing metallic dust, which would absorb solar heat and re-radiate it onto the surface, causing a rapid increase in temperature. This dust could come from a giant iron meteorite, they suggest.

Hoyle and Butler think that if a large enough meteor or asteroid of such composition impacted in Earth's northern hemisphere, it could throw up enough metallic dust to raise appreciably the temperatures of that part of the planet. The result would be a sudden melting of the surfaces of glaciers and bogs. Also, the heavy clouds of metallic dust would severely cut down the Sun's visible light, making it more difficult for the mammoths to see where they were walking.

"The need of every large animal to be constantly searching for food could then very well have led to their eventual blundering into crevasses, swamps, or bogs," say Butler and Hoyle. Then, when the metallic dust eventually filtered down to the surface, the temperatures would have dropped and the bogs and crevasses would have again frozen over, preserving the now-dead mammoths for today's explorers to find.

A Star is Born

Because a star is literally created during its proto-star stage, when a vast cloud of dust and gas contracts due to gravitational attraction, astronomers would dearly like to watch such a swirling cloud actually in the process of collapse. Unfortunately, such clouds are both not yet hot enough to glow and are already dense enough to be opaque to visible light from other sources. Optical telescopes are thus blind to the proto-star's internal behavior. In fact, they can only be seen at all when they are located against the background of a bright diffuse nebula, as a tiny dark spot. Radio telescopes, however,

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can gather in the weak radio signals emitted by heated molecules within the clouds.

Now, taking advantage of new, powerful techniques in radio astronomy, several astronomers have found a dark cloud of gas that appears to be a star in the process of being born.

"We believe we have isolated a proto-stellar object for the first time," says Patrick Palmer of the University of Chicago.

Reporting their work in the April 1, 1980 issue of the *Astrophysical Journal*, Palmer, Mark Morris of Columbia University, and B. Zuckerman of the University of Maryland explain that they studied a pre-stellar cloud in Orion by means of radio emissions from ammonia molecules within the cloud.

Palmer says that although ammonia was the first molecule detected between the stars, the radio emissions detected then were weak and "metastable." This means they could not be used to determine the temperature or density of the clouds they were found in. Without such information, pre-stellar clouds could not be separated from more ordinary agglomerations of interstellar gas.

Palmer, Morris, and Zuckerman observed ten different radio emissions from ammonia, all of which could be used for detailed study of the cloud and six of which had never before been detected. By tuning in on those emissions with the highly sensitive 100 meter-diameter radio telescope in Bonn, West Germany, the scientists found the dark cloud of gas to be about the same size, temperature, and density astronomers expect of a proto-star.

"Our first clue was its relatively high temperature of 220° above absolute zero," says Palmer. "Because most dark matter in space is only a few degrees above absolute zero, this gas must be heated, perhaps by compression from its collapse. The gas also seems to be either expanding or contracting at five or six kilometers per second. That is a natural speed for contraction of a collapsing cloud."

Palmer cautions that astronomers disagree somewhat on how small a cloud has to be before it is dense enough for gravitation to initiate a collapse and give birth to a new star.

"Every time a new, more powerful radio telescope comes along, someone finds a cloud smaller than has been seen before and calls it a proto-star," he says. "In fact most of those are far too large to form a single star or even a double star. But this cloud's small size — perhaps 20 times the size of the solar system — and its temperature and motions make me think it will almost certainly collapse to form a star. Of course that could take tens of thousands of years."

The proto-stellar cloud was first tentatively identified by the researchers as the object named IRc2, a source of infrared radiation. But Palmer has since used the Bonn radio telescope to determine that the radio emissions are probably coming from IRc4, a close neighbor of IRc2. That changes only the object's identity, not its nature, says Palmer.

Palmer says the signals received by the radio telescope were only one ten-millionth of a billionth of one watt in energy, necessitating the most sensitive of equipment. "We were also very patient listeners," he adds.

Strange Carbon in Space?

Carbon, essential to life as we know it, is one of the most abundant elements in the universe after hydrogen and helium. But there is a strange form of carbon, called *carbyne*, which contains unusual triply-bonded atoms. Chemists welcomed its discovery on Earth in 1968 because they had long wondered why an element with so rich a chemistry as carbon occurred in only two forms, graphite and diamond.

Carbyne has nonetheless remained a rarity. Only small quantities were produced in the laboratory, because extreme temperatures, above 4700° F, are required. Several types are known, and are used for lens coatings and other specialized applications.

But there were hints that nature knew an easy way to make carbyne. And now, this exotic form of carbon has been found in two primitive meteorites, and some of it may come from outside the solar system.

Radio astronomers can't see carbyne directly, but they have found its close relatives — cyanoacetylenes — in many cool, dark clouds in space. Adrian Webster of Cambridge University has speculated that even the interstellar dust lacing our Galaxy consists mainly of carbyne rather than graphite.

Now these hunches seem to have been confirmed by a group of scientists writing in the September 26 issue of *Science*. They succeeded in making carbyne at low temperatures, and they also found two kinds of apparently interstellar carbyne in meteorites.

The group was led by Roy S. Lewis and Edward Anders of the University of Chicago. In the first study, they were joined by Ryoichi Hayatsu, Robert G. Scott, and Martin H. Studier of the Argonne National Laboratory. In the second study, they worked with A. Greenville Whittaker and Ethel J. Watts of the Aerospace Corporation, El Segundo, California.

Hayatsu made carbyne by heating carbon monoxide and hydrogen with a chromite catalyst at 600°. Earlier he had shown that other catalysts under these conditions, such as clay or magnetite, gave a rich variety of organic compounds, resembling those in meteorites and interstellar clouds.

Using three different techniques, both groups also found carbyne in two primitive meteorites, one of which fell near Allende, Mexico in 1969, and the other near Murchison, Australia in 1968.

On heating to 500°, Allende carbyne gives off fragments of cyanoacetylene and clusters of two to ten carbon atoms. Hayatsu and his colleagues therefore suggest that the breakup of such unstable carbynes may be a source of interstellar molecules. They may also produce the bands of diatomic and triatomic carbon in comet spectra, whose origin has remained unexplained.

Where did these carbynes come from? Traces of trapped noble gases provide a clue, and actually got the scientists started on their search.

Some of the neon and xenon in Murchison carbyne has a very strange isotopic composition that cannot be explained by solar system processes. But it matches theoretical calculations for nuclear reactions in red giant stars. The Murchison carbyne grains were probably ejected from such stars, and eventually found their way into the forming solar system.

Evidently, carbynes are abundant in space. But they may not be so rare on Earth either. Last year, Whittaker found carbyne in six graphite samples from California, New York, and Ceylon. He pointed out that carbyne is quite easy to miss by the usual methods of chemical examination, being mistaken for "impure graphite."

The scientists conclude that "carbynes can form and persist in a wide variety of environments, and play an important role in nature. It is remarkable that so abundant and so well-studied an element as carbon should still yield surprises of this sort."

A Guide to Mars

An information packet on Mars, including unique 3-D views of the red planet, is now available from the Astronomical Society of the Pacific, a worldwide nonprofit educational organization.

The packet includes a complete map of Mars assembled by the U.S. Geological Survey from Mariner 9 photographs, a set of 3-D views (together with 3-D glasses) of the Martian surface taken by the *Viking* landers, an information sheet on what we have learned about our planetary neighbor, and a bibliography of further nontechnical readings and information sources.

These materials are part of a series of information packets being made available by the Society. Other topics in the series have included black holes, pseudo-science, and an introduction to astronomy.

Copies of the Mars packet can be obtained by sending $1 for postage and handling to:

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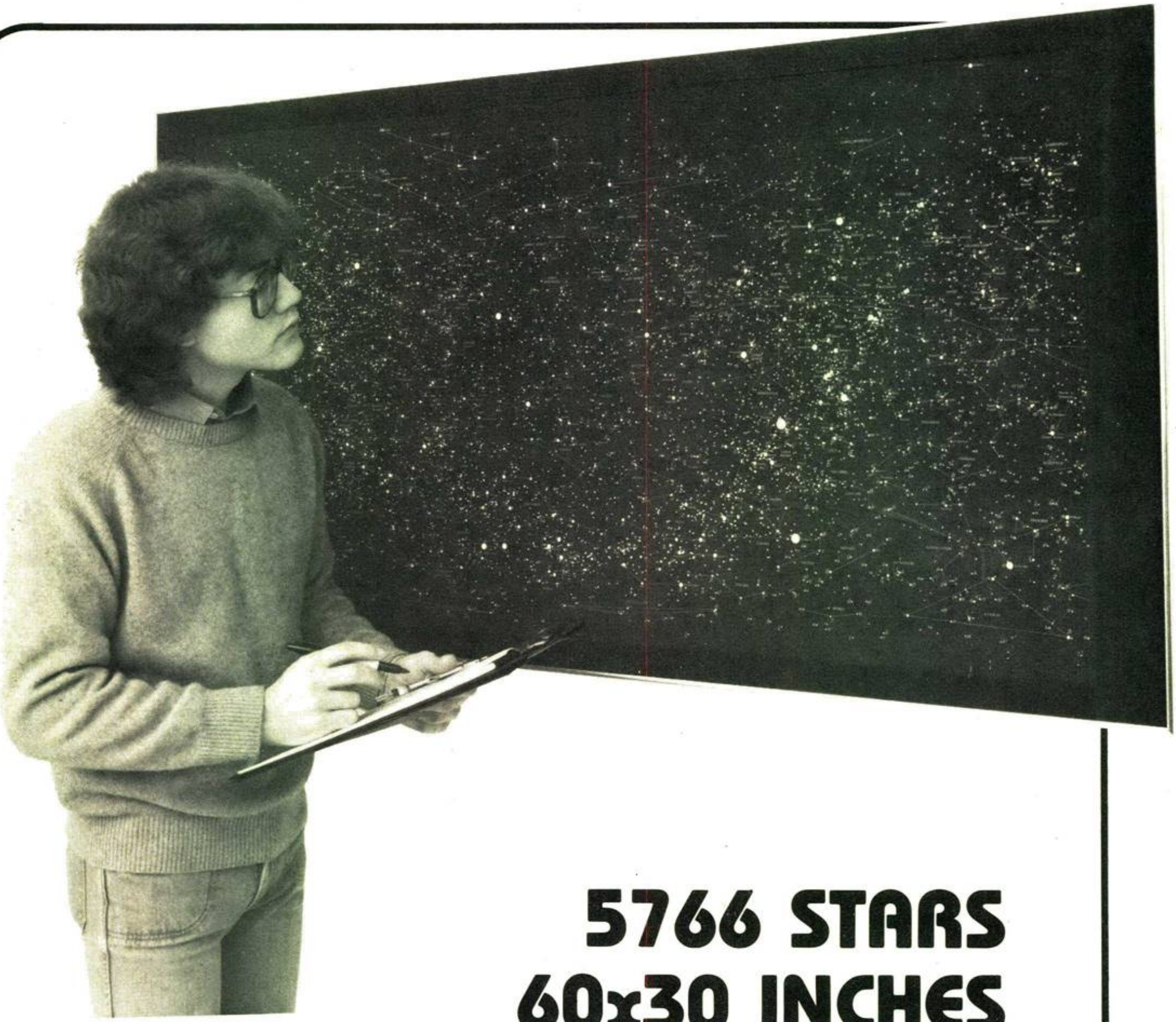

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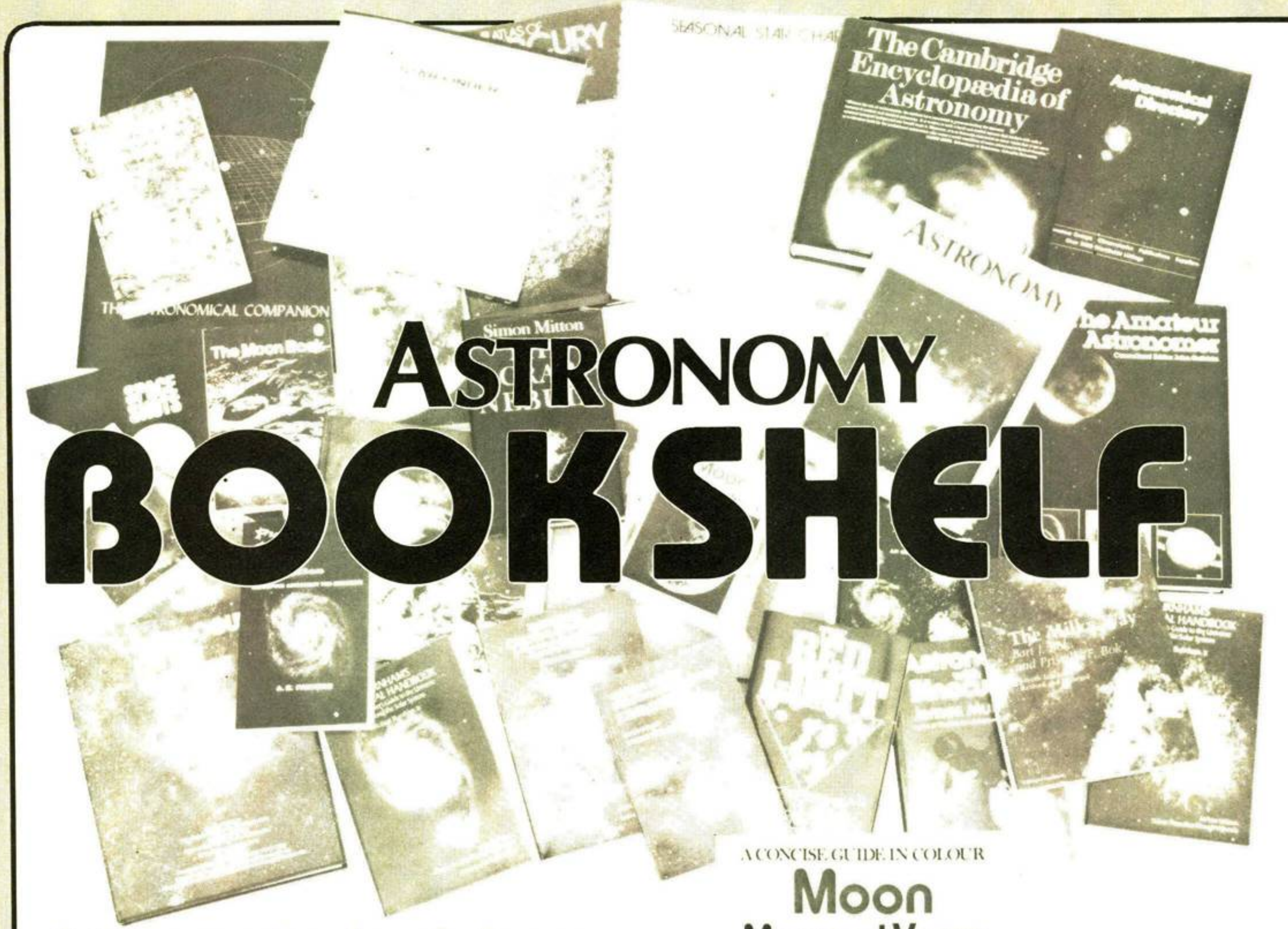
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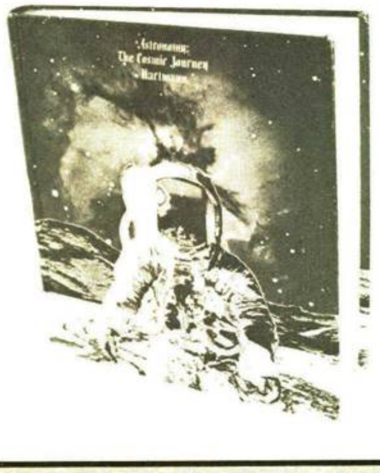
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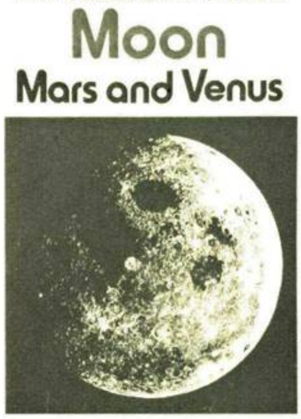
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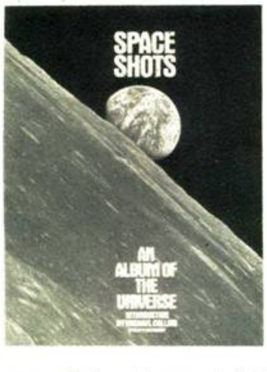

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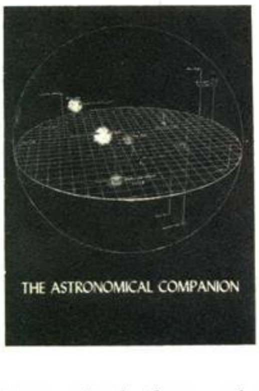

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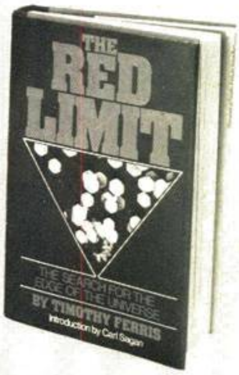
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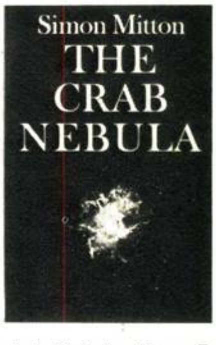

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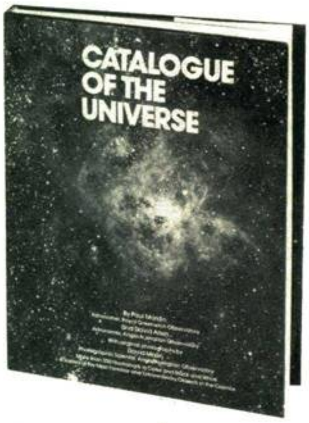

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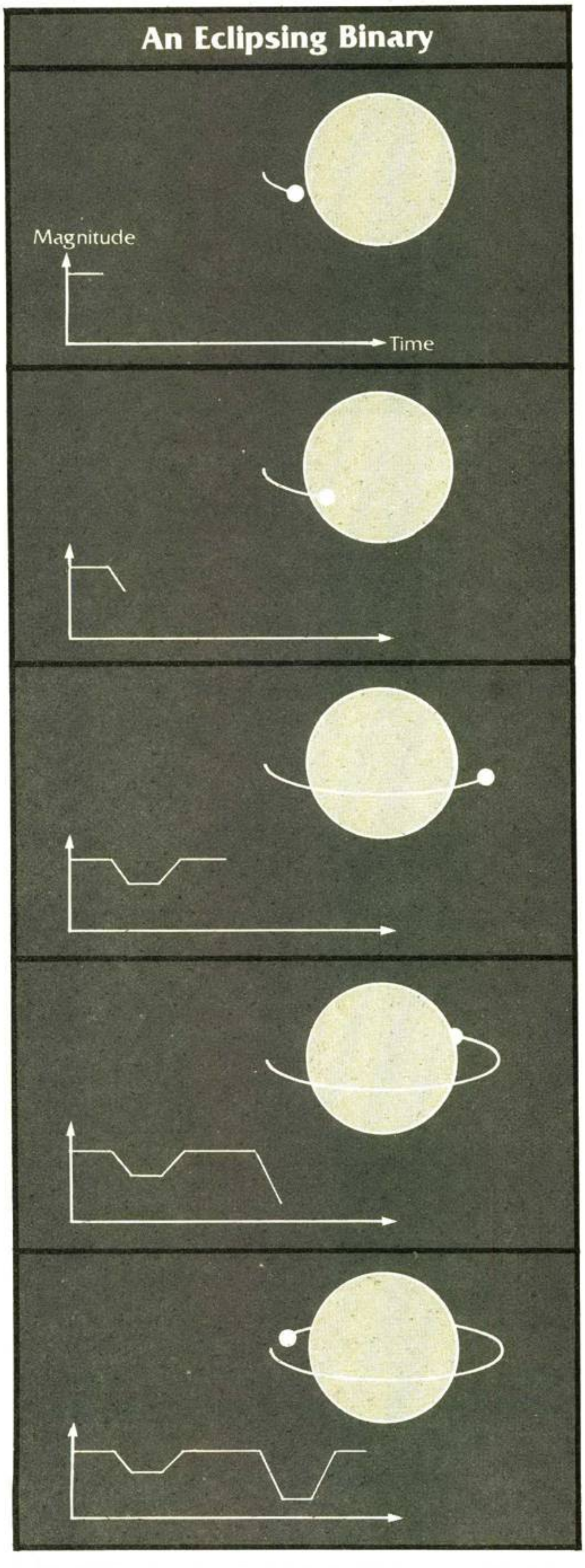
the Wink in the Demon's Eye

by Michael A. Seeds



In this idealized version of an eclipsing binary, a small hot star orbits a larger cool star. As the small star crosses in front of the larger one, the total brightness of the system decreases slightly as shown by the light curve. Later, when the hot star is eclipsed, the decrease is larger. Adapted from Michael Seeds, *Horizons: Exploring the Universe* © 1981 Wadsworth, Inc.

Algol, the eclipsing binary in the constellation Perseus, seems to be winking at astronomers as if it were enjoying a wry joke. Its regular variation in brightness is visible to the naked eye and may have been known to astronomers thousands of years ago, but the reason for the "winking" was not explained until 1782. Still, as recently as the 1950s, Algol was a paradox — according to the newly understood principles of stellar evolution, such a system couldn't exist. The Algol paradox was eventually resolved, and that resolution revealed how the stars in a binary system influence each other's evolution.

The First Eclipsing Binary

History credits Geminiano Montanari, mathematics professor at the Universities of Bologna and Padua, with the discovery of Algol's variability. From 1667 to 1669 he observed that it was sometimes fainter than usual, and on November 8, 1670, he watched the star fade to about one-third normal brightness and later recover. Although Montanari observed Algol's variation, he did not realize its fadings were periodic, nor did he understand why the brightness changed.

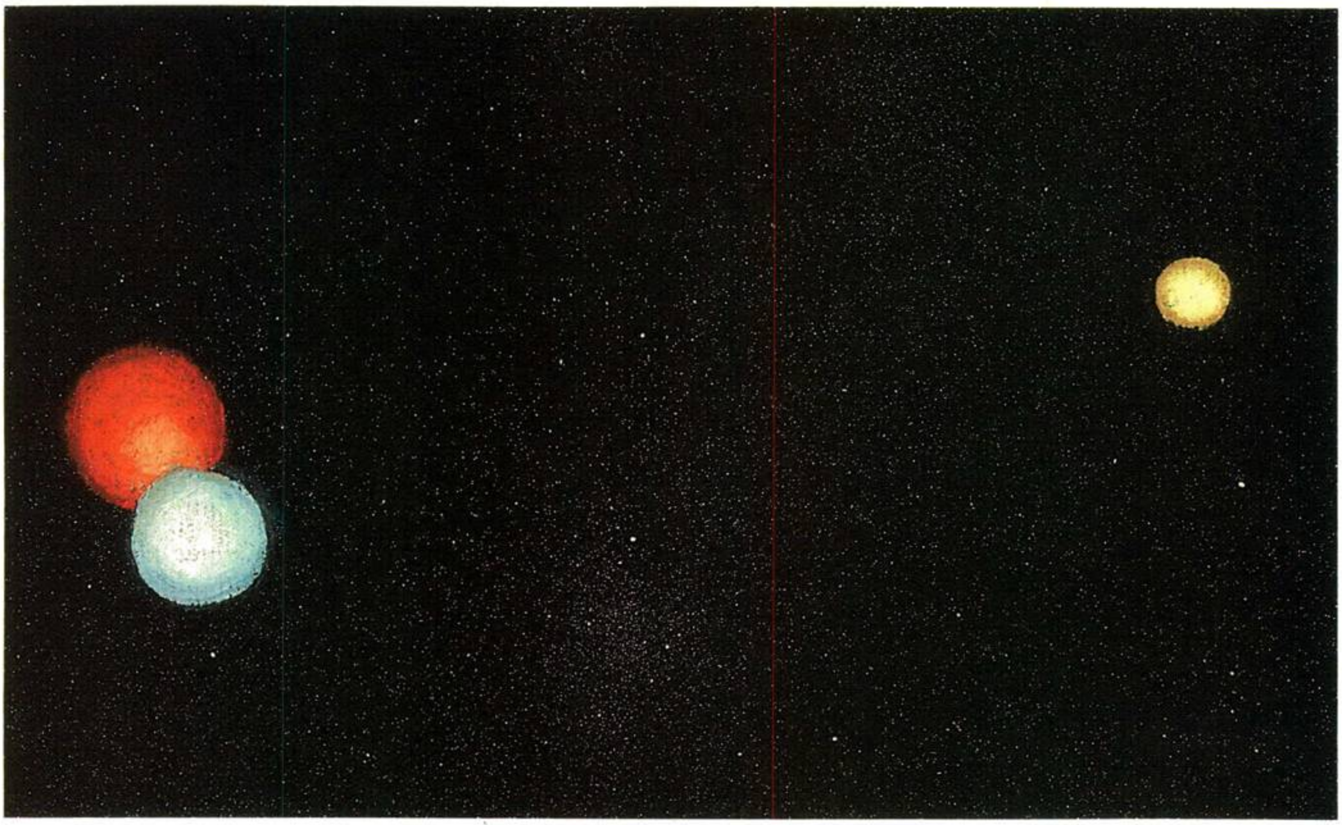
Credit for the first systematic study of Algol goes to the young Englishman John Goodricke of York. Though deaf and dumb and in chronic poor health, Goodricke was a winter of 1782-83, and quickly realized that its fadings were periodic, occurring every 68¾ hours.

Goodricke went on to offer two theories to explain the

Goodricke went on to offer two theories to explain the variations. First, he suggested that Algol might be a rotating globe marked irregularly by dark spots. As it rotated, it would present varying amounts of its bright surface toward the Earth, thus making its brightness fluctuate. As a second possibility, he suggested that a dark body might orbit Algol and regularly pass between the star and the Earth causing a temporary fading as it eclipsed the star. This second explanation is in fact correct, and it marks the first description of an eclipsing binary. Unfortunately, Goodricke did not live to continue his study of Algol. He died in 1786, not quite 22 years old.

Confirmation that Algol's fadings were due to eclipses had to wait 106 years while astronomy made three important advances. The first began in 1802 when William Hyde Wollaston discovered narrow, dark lines in the solar spectrum. He incorrectly interpreted these as the natural boundaries of the colors, but later studies revealed that they were produced by the atoms in the Sun. When astronomers examined the spectra of stars, they found similar spectral lines that originated in the stars themselves. Thus the first advance was the invention of *astronomical spectroscopy.*

The second advance occurred in 1842 when Austrian physicist Christian Doppler described a phenomenon now known as the *Doppler effect*. He explained that light leaving a star that is approaching the Earth will be perceived



The Algol system contains three stars. Algol A is a hot blue star orbiting close to a cooler red star whose near side is heated by the hotter star. The eclipses of this binary pair are responsible for Algol's regular fading. The third star is slightly hotter than the Sun and is not involved in the eclipses. Artwork by Michael Seeds.

by astronomers on Earth as having a slightly shorter (bluer) wavelength than light emitted by a stationary star. Similarly, light emitted from a star receding from the Earth will have slightly longer (redder) wavelengths.

This second advance was important because it meant that astronomers could measure a star's *radial velocity* — the velocity at which it recedes from or approaches the Earth — by measuring the wavelengths of the lines in its spectrum. For example, if a star's spectrum contains lines shifted slightly to the red, then the star is receding from the Earth, and the larger the shift, the larger the velocity.

However, before astronomers could analyze the spectrum of Algol for Doppler shifts, they had to wait for a third advance in astronomical techniques — the invention of *astronomical photography*. Nineteenth century astronomers observed stellar spectra visually, peering through spectroscopes at the faint smears of color that are stellar spectra. Just seeing spectral lines through such a spectroscope is a challenging task. Measuring their wavelengths is nearly impossible. Such astronomers as Sir William Huggins at his private observatory in England and J. E. Keeler at Lick Observatory were able to measure Doppler shifts for a few stars, but accurate observations of Doppler shifts require a permanent photographic record of the spectrum.

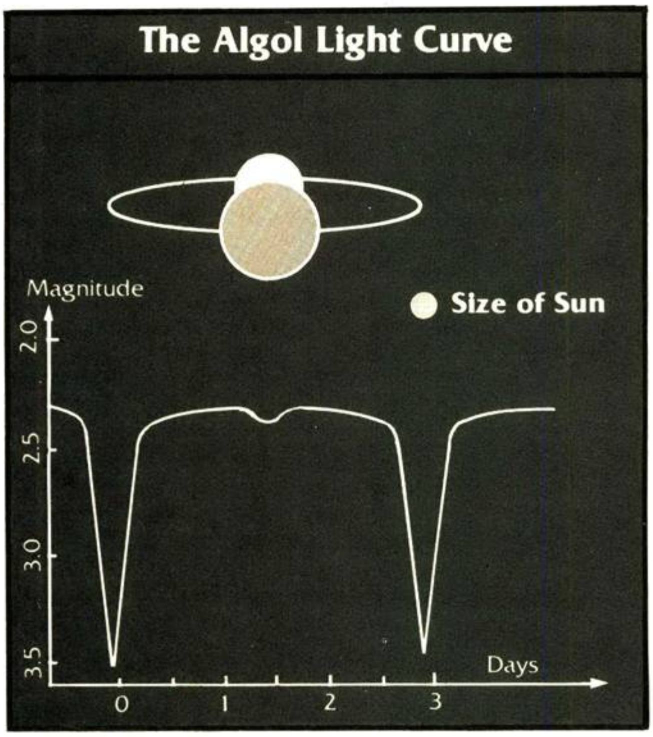
The first astronomical photographs were daguerreotypes taken in the 1840s of the Moon, the Sun, and the solar spectrum. However, the much fainter stellar spectra could not be recorded until the invention of more sensitive photographic materials. Using wet plates, Huggins in 1863 and Harvard's Henry Draper in 1872 photographed some of the first stellar spectra. But it was not until 1889 that H. C. Vogel at Potsdam Observatory was able to photograph stellar spectra on dry plates and accurately measure stellar radial velocities. This development in astronomical photography, coupled with the two previously mentioned advances, paved the way for confirmation of Goodricke's theory that Algol was orbited by a dark companion.

When Vogel photographed the spectrum of Algol, he found that the spectral lines were shifted, sometimes to the red and sometimes to the blue. This indicated that Algol was in motion, orbiting around a common center of mass in a system of two stars. The dark body in Goodricke's theory was merely a star, too faint for its spectral lines to register on the photographic plate.

In the half century that followed Vogel's work, astronomers came to understand eclipsing binaries rather well — or at least they thought so. Binary stars, systems in which two stars orbit each other, are very common. More than half of all stars are members of multiple star systems. In some cases, the stars are far enough apart to be separately visible through a telescope and are therefore called *visual binary* stars. In most cases, however, the stars orbit so close to each other they appear as a single point of light through even the largest telescopes, and it is only by the changing Doppler shifts in the spectrum that we recognize that they are binaries. Such systems are called *spectroscopic binaries*. Only rarely are such systems eclipsing binaries.

In order for the stars in a binary system to eclipse, they must pass in front of each other as seen from Earth. That means their orbit must be tilted edge-on to Earth. In that case, as one star crosses in front of the other, the total amount of light is reduced and we see an eclipse. Half an orbit later, the two stars have reversed their positions and we see another eclipse. Astronomers call the deeper eclipse *primary eclipse*, and the shallower, *secondary eclipse*.

The study of eclipsing binaries that began with Montanari in 1667 has now become an important part of modern astronomy. The analysis of the light curve and radial velocities of an eclipsing binary can reveal both the radii and masses of the stars. This is critical information because there is no other way to get stellar masses, and the only other way to measure stellar radii (interferometry) is limited to only the largest and nearest stars. This alone


The Algol Light Curve

Algol is an eclipsing binary in which the eclipses are only partial — the stars do not cover each other completely.

makes eclipsing binaries a fascinating subject, but Algol has its own special mysteries.

The Stars in the Algol System

In contrast with the past, we now understand Algol's stars rather well. Following Vogel's work, generations of astronomers observed the system and found the orbits, masses, sizes, and spectral types of the stars. As they understood Algol better, they discovered it was a highly complex system, though they little suspected how paradoxical it would prove to be.

In fact, the Algol system contains *three* stars — Algol A and Algol B are a close pair whose orbital motion produces the eclipses. Algol C orbits farther from the system's center of mass and is not involved in the eclipses.

Algol A, referred to as the *primary* star (not to be confused with primary eclipse), is a B8 main-sequence star about 3.7 times the Sun's mass and about 3 times its radius. It is about 90 times more luminous than the Sun, and most of the light we receive from the system comes from the primary. Algol B, referred to as the *secondary* star, is a K0 subgiant — that is, it is not a main-sequence star, but is not as large as a normal K0 giant. It is about 0.8 times the Sun's mass, about 3.4 times its radius, and only 3 times its luminosity. The centers of these two stars are separated by only 6.5 million miles, about 1/14 the separation between the Earth and the Sun. As seen from the Earth, the stars are never more than 0.002 second of arc apart and thus they appear as a single point of light.

Algol A and Algol B orbit each other with a period of 2.867 days — about $2^{d}20^{h}49^{m}$. Although both stars move in orbits around their common center of gravity, it is easier to think of their motions if we imagine that the more massive star (the primary) is fixed in space and that the secondary follows an orbit centered on the primary. This is called the *relative orbit* because it is drawn relative to the primary star.

Primary eclipse occurs when the K0 star crosses in front of the B8 star. The orbit falls 8° short of being perfectly edge-on to Earth, however, so the stars do not cross directly in front of each other. Even at the middle of primary eclipse, 21% of the B8 star remains visible. This explains why the eclipses in Algol's light curve are not flat on the bottom. They are rounded because there is never a time during eclipses when the amount of the B8 star covered remains constant.

Secondary eclipse occurs when the K0 star passes behind the B8 star. Because the K0 star is less than half the temperature of the B8 star, its surface is only about 3% as bright. Covering a portion of its surface reduces the total brightness of the system only slightly and secondary eclipse is not very deep.

Algol A and Algol B are so close together that they are subject to a peculiar effect common to close binaries. The so-called *reflection effect* appears in the light curve as a gradual brightening of the system before and after secondary eclipse. This arises because the hot star heats the near side of the cool star, making it brighter on that side. In fact, it is 70% brighter on the side toward the primary than on the side turned away. As secondary eclipse approaches, the system rotates so the brighter side of the K0 star is toward the Earth and the total brightness increases.

Another effect visible in Algol's light curve is *limb darkening*. The eclipses, both primary and secondary, begin gradually due to the variation in intensity over the visible disk of the stars. In astronomy, the edge of the visible disk of a planet, moon, or star is its limb, and limb darkening refers to the decrease in intensity near the limb. Limb darkening is evident on photographs of the Sun, for instance. Near the center of the Sun's disk we look straight down into its atmosphere, but near its limb we look into its atmosphere at a shallow angle and we cannot see as deeply. The light we receive from the Sun's limb comes from higher layers in its atmosphere that are cooler and therefore less bright than the deeper, hotter — and brighter — layers visible at the center of the disk. This limb darkening is also present in other stars such as Algol A and Algol B.

The Third Star

Algol's light curve can tell us a great deal about the eclipsing stars, but Algol C does not enter into the eclipses, and that makes it more difficult to study. Algol C was first discovered because of a variation in the times of the eclipses. Over the years astronomers noticed that primary eclipse sometimes occurred as much as six minutes too early and at other times six minutes too late. The effect varies with a period of 1.862 years and is due to the presence of Algol C.

If Algol A and Algol B were the only members of the system, eclipses would always occur at the predicted times, but Algol C orbits the center of mass of the system at a distance of about 0.55 astronomical unit, or a little over half the Sun-Earth distance. This means that the center of mass of the Algol A-Algol B system must swing around the center of mass of the entire system with a period of 1.862 years. Sometimes the eclipsing pair of stars is 1.8 million kilometers (2.9 million miles) closer to us than normal and the light takes six minutes less to reach Earth. Thus eclipses occur six minutes early. Later, when Algol C has moved through half of its orbit, the eclipsing pair of stars is 1.8 million kilometers farther away than normal and light takes six minutes longer to reach Earth. Then eclipses occur six minutes late. This is called the *light time effect* and is clear evidence that a third star is present.

Except for the light time effect, Algol C is very hard to detect. As seen from Earth, it is never more than about 0.02 second of arc from the eclipsing pair of stars and thus is never visible separately. In addition, Algol C is not as bright as the B8 star. Algol C is about 1.7 times the Sun's mass, roughly 1.5 its radius, and only about four times its luminosity. Only during primary eclipse, when the brightness of the brilliant B8 star is reduced, are spectral lines due to Algol C visible.

Apsidal Motion

Another little trick Algol has played on Earth's astronomers has to do with the timing of the secondary eclipse and the shape of the orbit. Recall that we can think of Algol B as moving in a relative orbit about Algol A. If this orbit were perfectly circular, then secondary eclipse would always occur precisely half an orbit after primary eclipse — that is, halfway between primary eclipses.

However, the secondary eclipses in Algol's light curve do not always occur at the halfway point. This could be due to an elliptical orbit. In such an orbit, Algol B would move faster when it was closer to the other star and slower when it was farther away. This might mean, for instance, that it would take longer to go from primary to secondary eclipse than from secondary back to primary, and thus the secondary eclipse would be consistently late.

But Algol's secondary eclipses aren't consistent. They can be as much as 43 minutes early, and at other times as much as 43 minutes late. Careful observation has shown that this effect varies with a period of 32 years. It is tempting to explain this as the influence of a fourth star, but that won't work because a fourth star would affect the times of primary eclipse too.

The true explanation lies in the proximity of the two stars. They are so close together they distort each other tidally and are not perfectly spherical. Tidal forces between the non-spherical stars cause the relative orbit to rotate. The long axis of an elliptical orbit is called the *line of apsides*, and the motion of the orbit is called *apsidal motion*. Because the long axis of Algol's orbit swings around once every 32 years, the time of secondary eclipse changes slightly with the same period.

Apsidal motion gives us a chance to peer inside the stars and study their internal structure. If a star has most of its mass concentrated near its center, then tidal forces won't distort it much from spherical and its orbit won't be subject to rapid apsidal motion. However, if a star's mass is not highly concentrated toward its center, then it can be more easily distorted into an egg shape and apsidal motion will change its orbit more rapidly. From mathematical models of stars, astronomers can compute the degree of mass concentration in different kinds of stars, and then, from celestial mechanics, calculate the rate of apsidal motion that should occur in a given binary system. These predicted rates agree very well with observations and confirm that the stellar models on which most of modern astronomy is based do indeed describe the interiors of stars.

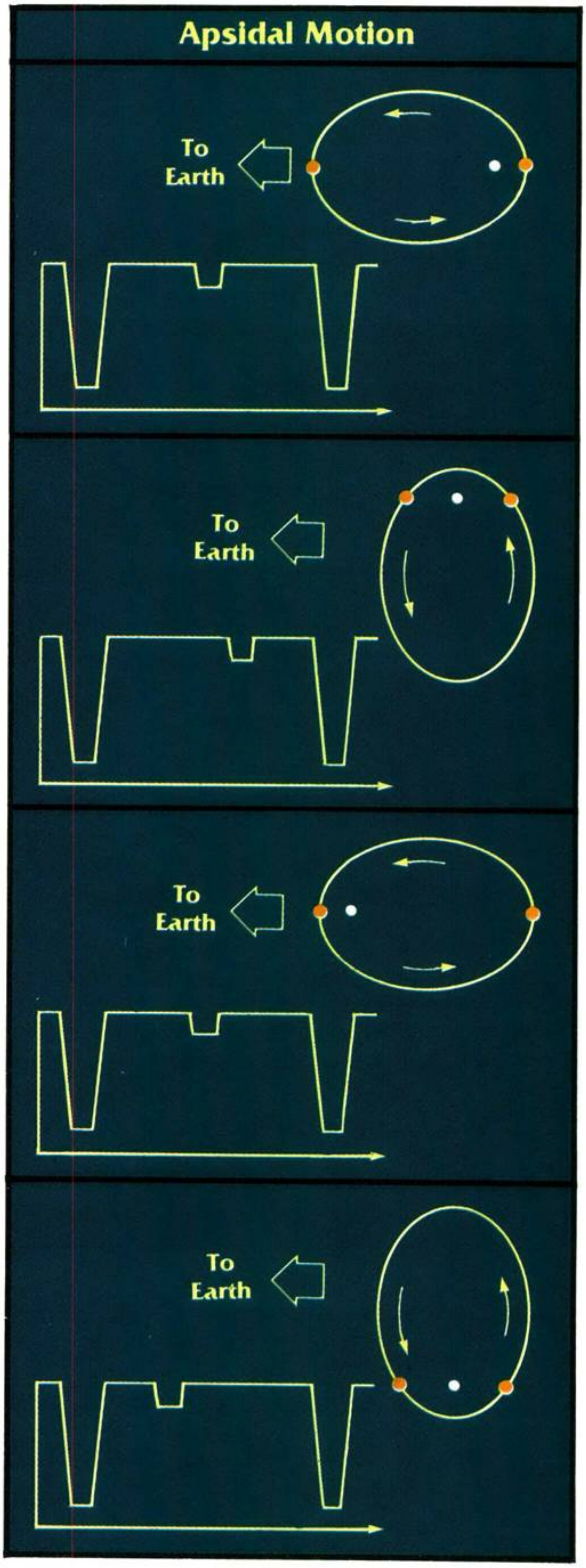
The Algol Paradox

Apsidal motion, the light time effect, limb darkening, the reflection effect — all of these are understood, and that might suggest that Algol hides no more surprises. But in 1950, Algol became the center of an astronomical problem now called the *Algol Paradox*. Put simply, the theory of stellar evolution, then in its infancy, predicted that systems like Algol could not exist.

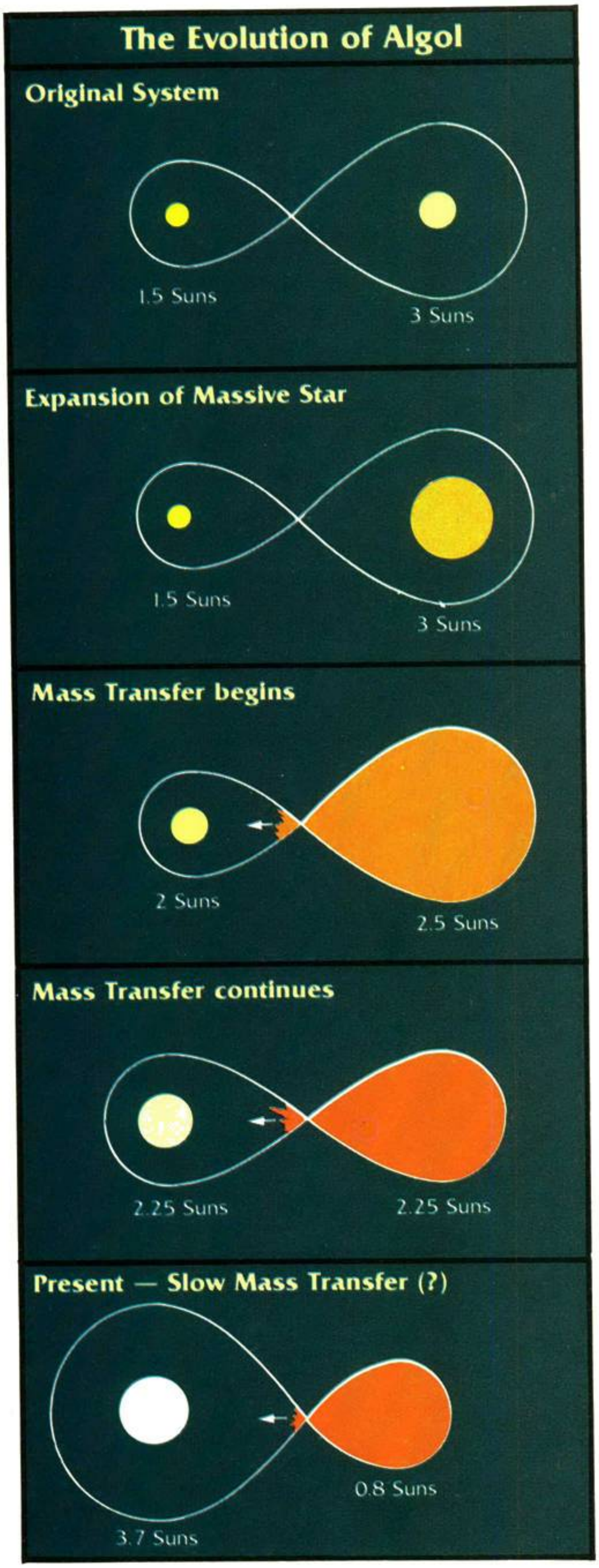
By 1950, astronomers had traced the broad outlines of stellar evolution. Stars on the main sequence burn hydrogen in fusion reactions at their centers, keeping their interiors hot and at a high enough pressure to support the weight of their outer layers. Since more massive stars have more weight to support, they must burn their fuels faster and make more energy. This leads to two predictions. The more massive a main-sequence star is, the more luminous it is. Thus a B star, being more luminous, must be more massive than a K star. Also, the more massive a star is, the sooner it must consume its fuel and die.

The details of stellar death were not known in the 1950s, but astronomers did know that as a main-sequence star exhausted the hydrogen at its core, it had to expand and become a giant.

These principles of stellar evolution did not seem to fit the observed properties of Algol and of similar binary systems. The Algol type binaries have a main-sequence primary of spectral type B5 to A5, and a secondary that is a subgiant usually of spectral type G to K. In each case, the



A star moving in an elliptical orbit around another star has a higher velocity when the stars are close and a lower velocity when they are farther apart. In a system such as Algol, where tidal forces make the elliptical orbit rotate, the position of secondary eclipse relative to primary eclipse can change. This is referred to as *apsidal motion*.



The evolution of the Algol system can be summarized by this series of views. The secondary (right) was originally more massive than the primary (left). As the secondary swelled into a giant, it filled its Roche lobe and rapidly transferred mass to the primary. The primary became more massive and the secondary less massive, until they reached their present masses. Some mass transfer is probably still occurring.

more massive star is still on the main sequence, and the less massive star has expanded to become a subgiant. Clearly the stars in Algol had to form together and therefore they must be the same age. If that is the case, then the principles of stellar evolution predict that the more massive star will become a giant first. The Algol Paradox is that the less massive star has become a giant (or in this case, a subgiant) before its more massive sibling.

The same year the Algol Paradox was proposed, the seeds of its solution were sown, and by the early 1960s the solution was clear. The two stars in Algol are so close to each other they have transferred mass from one star to the other, drastically changing the evolution of each star.

To understand what happened in Algol, we must discuss the Roche lobes around a pair of binary stars. When two stars orbit each other they exert tidal forces affecting the motion of matter in the system. The *Roche lobes* are dumbbell-shaped regions around the two stars that mark off the regions of space that the stars can control gravitationally. A blob of gas floating just inside a Roche lobe is bound to the star at the lobe's center, but if the gas blob crosses the Roche lobe boundary, the star loses control of it. The gas may be drawn to the other star or

Who Really Discovered Algol?

You can observe the variation of Algol yourself. (See Through the Eyepiece this month for a star chart and the dates and times of eclipses.) Montanari is given credit for discovering Algol, but that may be nothing more than an accident of history. His records may simply be the oldest to survive. Algol's eclipses are so easily observed it is hard to believe no one noticed them before. And yet there is no known earlier record of any change in Algol's brightness, even though some ancient astronomers, especially the Arabs, were excellent observers.

Some historians of science claim that the name *Algol* is itself a record of its peculiar behavior. "Algol" comes from the Arabic *Al Ra's al Ghul* meaning "the Demon's Head." These historians argue that the winking star was associated with the tradition of the evil eye and was therefore given a sinister name. If this is true, Arab astronomers clearly knew of Algol's variation.

However, the Arab astronomers did not invent the constellations. They adopted them from the Greeks. In Greek constellation lore Algol was the head of Medusa, one of the three Gorgons — ugly sisters who shared one eye and one tooth and had hair of snakes. One look at their faces was enough to turn mortals to stone. Perseus avoided this fate by gazing at Medusa's reflection in his polished shield and was thus able to slay her. The Greeks saw Perseus in the sky clutching Medusa's severed head.

When Arabian astronomers adopted the colorful Greek constellation, they looked in their own cultural tradition for a monster similar to Medusa. They settled on the Ghul (source of our word "ghoul"), a female demon and sorceress capable of assuming monstrous shapes and fond of eating corpses. If the Arab astronomers merely replaced Medusa with the Ghul, then they might not have known of Algol's variation.

Perhaps the name Algol is not significant, but we can still wonder why the original designers of the constellations chose to place the head of a monster at the location occupied by the winking star. Did they know of its variation, or is it just a coincidence? That is a secret Algol may keep forever.

ejected from the system.

The presence of Roche lobes in a binary system is not important unless the stars are close together. If they move in small orbits, their Roche lobes are small — not much larger than the stars themselves. When a star begins to expand, it can push its surface outside its Roche lobe and lose control of that material. The surface of the star can then flow toward the other star in the binary and fall into that star from the point where the two Roche lobes touch. Thus the evolving massive star can transfer some of its mass to its companion.

The rate of this mass transfer can be quite rapid at first. Due to the conservation of energy and angular momentum in the binary system, the orbits shrink as the mass transfer makes the stellar masses more nearly equal. This makes the Roche lobes shrink and makes the mass transfer go even faster. In addition, the loss of the star's outer layers may not make the star contract. In fact, in some circumstances, the star may expand faster as its surface slips away. For example, a star could transfer two-thirds of its mass to its companion in only 100,000 years — a mere moment in the life of a star. This rapid mass transfer ends soon after the stars become equal in mass. Then further mass transfer makes the stars move apart and the Roche lobes grow larger. However, the mass transfer may go on for a long time if the expanding star continues to evolve, slowly expanding and pushing more of its mass out of its Roche lobe. This slow, evolutionary mass transfer typically transfers 10^{-6} to 10^{-9} solar masses per year. This is only the mass of the Earth or less.

How did mass transfer affect the evolution of Algol? We might guess that the system originally contained a three solar mass star with a 1.5 solar mass companion. After about 600 million years of burning hydrogen in its core, the more massive star began to expand into a giant. But the stars were so close together, the Roche lobes were small, and the evolving star began to lose mass to the 1.5 solar mass star. The mass transfer went rapidly at first and then more slowly. Now the star that was originally three solar masses has wasted away to a 0.8 solar mass subgiant. The star that was originally 1.5 solar masses has grown into a 3.7 solar mass star, still a main-sequence star. This theory assumes no mass was lost from the system, but even if some mass escaped, the theory explains why the less massive star in the Algol system has evolved before its more massive companion. This resolves the Algol Paradox.

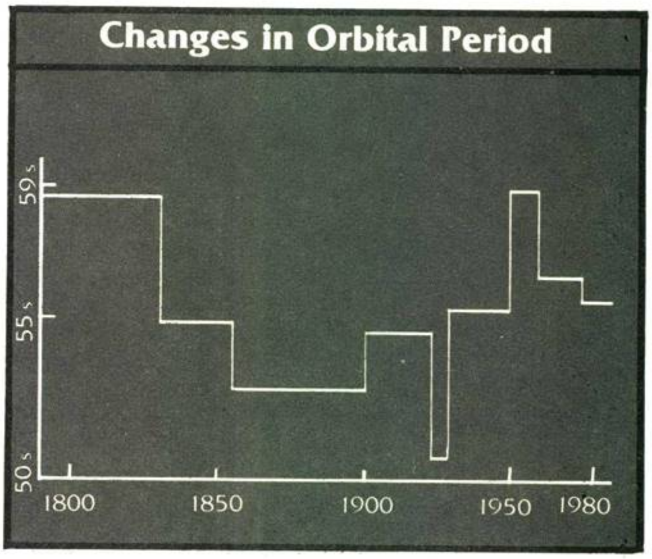
Algol Today

The era of rapid mass transfer is over for Algol, but slow mass transfer may still be occurring as the K0 star continues to evolve and expand. Observations show that it does fill its Roche lobe. But what evidence do we have for continuing mass transfer? In fact, Algol has been behaving very mysteriously for at least the last decade, and that behavior may be related to the continuing expansion of the K0 star.

One oddity about Algol is that it is a source of radio flares. First discovered in the late 60s and early 70s, the radio emission is highly variable with roughly a dozen outbursts a year strong enough to be called flares. Some other close binary systems are known to produce radio flares, but Algol is the most active. These flares do not seem to be affected by the eclipses, and measurements of the size of the emitting region suggest it is no more than 0.05 astronomical unit in diameter. This is roughly the size of one of the stars. One theory speculates that mass is streaming irregularly from the K0 star and falling into the B8 star where it excites the emission of radio signals.

The mechanisms that could produce the radio flares should also produce X-rays, and, in fact, Algol *is* a source of X-rays. These were first detected in 1976 by the Small Astronomy Satellite-3 and the Orbiting Solar Observatory-7. This detection of X-rays supports the theory of continuing mass transfer in the Algol system.

Another observation that hints at mass transfer is the changes in Algol's orbital period. These changes were originally thought to be a light time effect due to the presence of a fourth star, but they are now believed to occur suddenly rather than gradually, and that rules out a light time effect. The period changes amount to only a few seconds and have occurred about once every 25 years since the first precise observations in 1784. These changes could be due to the occasional transfer of large amounts of mass from the K0 star to the B8 star, or the ejection of mass from the system.



The orbital period of Algol is subject to changes now believed to occur suddenly, perhaps due to irregular mass transfer from the secondary. The most recent change occurred in the mid 1970s.

Algol's Future

Algol's distant future may be even more interesting then the mysteries of its past and present. According to current theory, the K0 star must eventually collapse into a white dwarf, and at that point mass transfer must stop. However, the primary star cannot continue to burn hydrogen at its center forever, and when it runs out of fuel, it too must swell into a giant. As it pushes its surface outside its Roche lobe, mass should begin to flow back to the white dwarf. That could create a fascinating sequence of events.

Binary systems in which an evolving giant transfers mass onto a white dwarf are believed to be the source of nova explosions. The material that accumulates on the surface of the white dwarf contains a great deal of unburnt nuclear fuel, and when that fuel becomes dense enough and hot enough to ignite, it can explode, driving away the white dwarf's surface in an expanding cloud of glowing gas. It is the light from this expanding shell that we see as a nova. If the mass transfer resumes after the eruption, more matter can accumulate on the white dwarf's surface and eventually produce another explosion. Recurrent novae appear to be binary systems in which the material accumulates rapidly and causes successive nova outbursts.

Will Algol become such a nova? How many hundred million years must we wait for the first explosion? How often might the outbursts recur? No one knows. The evolution of close binary systems is one of the frontiers of modern astronomy. Judging by Algol's participation in the past development of astronomy, it is not surprising that the Eye of the Demon is a central figure in this newest adventure.

Michael A. Seeds is an associate professor of astronomy and director of the Joseph R. Grundy Observatory at Franklin and Marshall College in Lancaster, PA. His primary research interest is in photoelectric photometry, and he is currently developing a computer controlled photometer. He is the editor of **Astronomy: Selected Readings** *and the author of* **Horizons: The Exploration of the Universe**, *an introductory textbook.*

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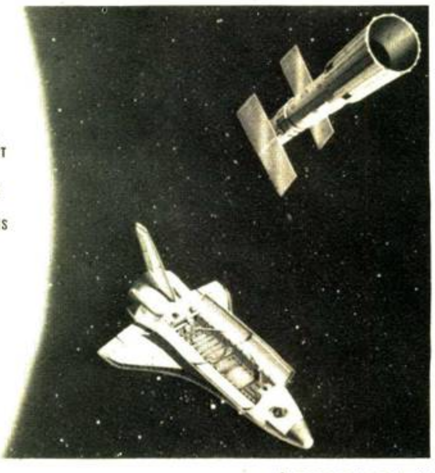

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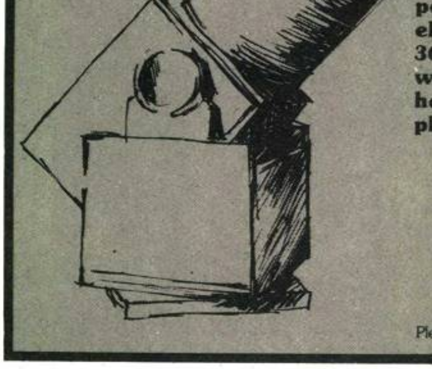

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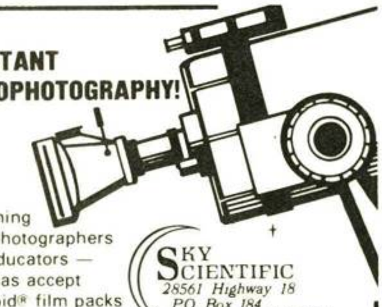

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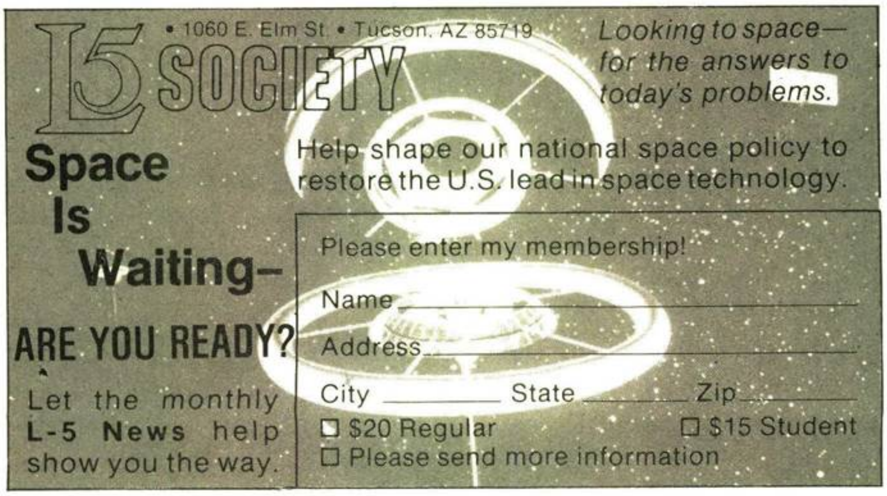

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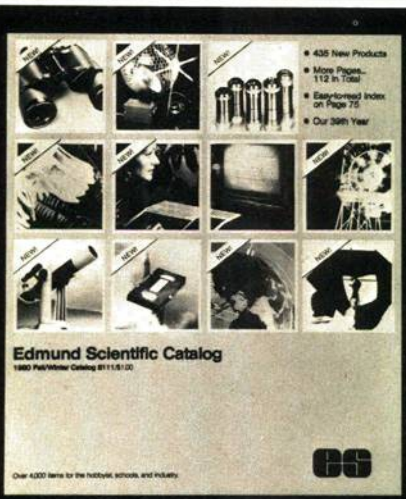

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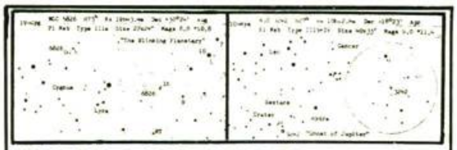

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through the eyepiece

December skies are often cloudy in many parts of North America. If this happens to you, you'll miss a lot this month!

Mercury

As the diagram on page 105 of November's Through the Eyepiece showed, Mercury will remain visible in the pre-dawn sky until about the middle of December. Currently on the downward leg of its brief arc in the east-southeast, Mercury's low elevation forces you to find an observation spot with a very low horizon in this direction.

Those who locate it with their telescope will see a yellowy, gibbous ball about five seconds of arc in diameter and of -0.5 magnitude. Because Mercury lies so low, your view of it will be poor — there's a thick layer of soupy, disturbed air between it and you.

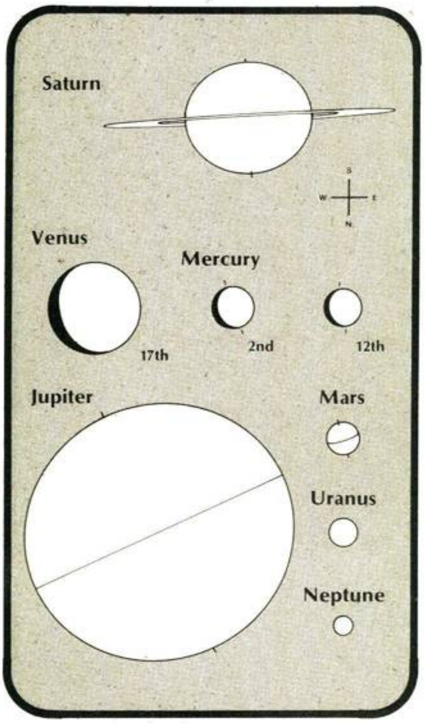
On December 11th, Mercury will be 4° 47′ north of Antares. The exact moment of closest approach (13:06 UT) about coincides with sunrise for the middle of the continent, but viewers anywhere can see something of it.

On the 28th (at around 11:50 UT), Mercury will pass in front of the globular cluster M-28 in Sagittarius. Unfortunately, the one problem with observing this rare event is that it happens just three days before superior conjunction. Mercury then will be only 7^m and 6^s of right ascension west and 1° 37′ 21″ of declination south of the Sun's center. Practically speaking, you aren't likely to see the cluster — even if you do find Mercury.

Star-clouds and dust! Alfred Lilge's superb shot of the Milky Way's center in Sagittarius wins the "Best Astro-Photo" competition for December. Using a 4 x 5 press camera, 098 emulsion plates, an orange filter, and a 150 mm lens at f/5.6, the 1 hour exposure was centered at 17h45m, -25°. (North is at left.)

In addition, the time of conjunction with the cluster comes shortly before sunrise in North America. But why not try anyway?

On the last day of the year, Mercury reaches superior conjunction with the Sun. Its next appearance will be in the evening sky in January and February 1981, around the time of greatest eastern elongation (February 2).



Venus

Also dropping downward toward the horizon (and eventually, the Sun), Venus still shines very prominently in the eastern sky — even though its elevation there is half what it was at maximum back in September. Despite this, it still blazes out at -3.4 magnitude, less than a magnitude dimmer than its greatest brilliance.

Telescope users who have looked for and found Venus in the daytime often report seeing details in the smooth white cloud cover that hides the surface. Typically taking the form of faintly darker patches on the ball or slight irregularities in the terminator, such markings might become visible when the bright light of the sky has reduced the extreme contrast you normally have when observing Venus after sunset.

The time-honored way to find the planet in daylight is to offset from the Sun — but, as always, TAKE CARE! The amounts to move the telescope (starting at the Sun) are: $2^h 02^m$ west, 9° 07′ north (December 1st); $1^h 57^m$ west, 6° 31′ north (11th); $1^h 50^m$ west, 3° 51′ north (21st); and $1^h 42^m$ west, 1° 18′ north (31st).

At 1:49 UT on December 16th, Venus will pass 1° 14′ to the north of Uranus. Since at that moment both lie well below the western horizon as seen from North America, you'll have to look for them after the event — before the following sunrise. Forty-five minutes before local sunrise on the 16th, they'll be about 13° to 14° high in azimuth 129° (roughly southeast).

Another Venus conjunction takes place with Antares at 3:55 UT on December 25th. Like the meeting with Uranus, this comes at a time when both objects are well below the horizon. Look in the southeast for them before sunrise on the 25th (this may be asking a lot on Christmas morning!).

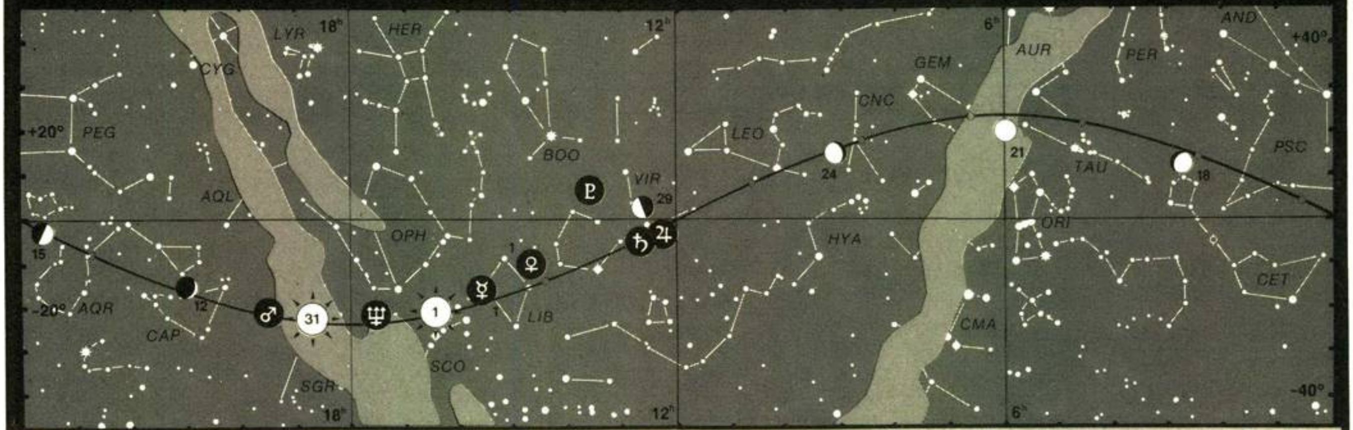
Earth

On the 21st of December, at 16:56 UT, the Sun reaches its farthest southern declination and begins moving back northward. This marks the beginning of winter for the northern hemisphere, summer in the southern.

Moon

During its monthly course, the

planetary data december 1980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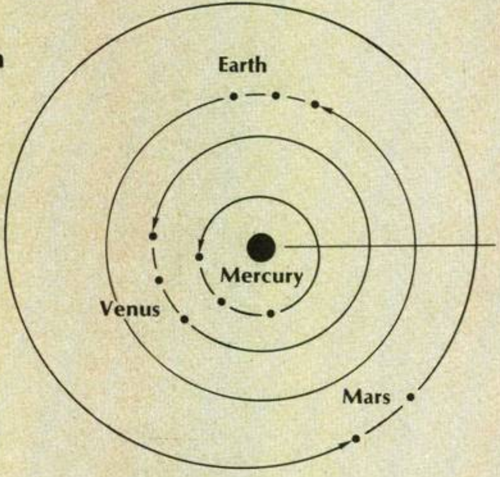
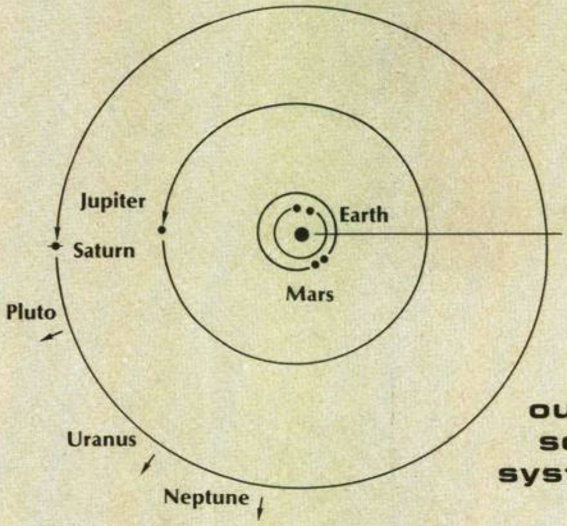
6h

inner solar system


Earth
Mercury
Venus
Mars


Jupiter
Saturn
Earth
Mars
Pluto
Uranus
Neptune

outer solar system

		Date	Mag.	Angular Size	% Illum.	Distance (AU) from: Earth	Sun	Longitude: Heliocentric	Ecliptic	R.A. (1981.0)	Dec
Sun		10	--	32.5′	--	0.98	--	--	258°05.9′	$17^h08.2^m$	-22°54.4′
		20	--	32.6′	--	0.98	--	--	268°16.3′	17 52.4	-23°25.7′
Mercury	☿	10	-0.5	4.9″	94%	1.36	0.44	219°33.6′	245°57.9′	16 18.3	-21°02.2′
		20	-0.7	4.7″	98%	1.43	0.47	248°12.2′	261°26.6′	17 24.3	-23°58.4′
		30	-0.8	4.6″	99%	1.44	0.46	275°52.5′	277°13.1′	18 33.6	-24°52.5′
Venus	♀	10	-3.4	11.9″	88%	1.41	0.72	189°10.4′	229°18.2′	15 10.9	-16°07.7′
		30	-3.4	11.2″	92%	1.50	0.72	221°21.1′	254°13.4′	16 53.8	-21°37.2′
Mars	♂	15	+1.4	4.2″	98%	2.23	1.40	304°29.8′	287°09.5′	19 16.8	-23°23.7′
Jupiter	♃	15	-1.5	35.1″	99%	5.61	5.44	177°48.8′	187°26.4′	12 30.9	-1°59.4′
Saturn	♄	15	+1.1	17.1″	100%	9.74	9.53	183°00.6′	188°16.9′	12 35.6	-1°21.9′
Uranus	⛢	15	6.1	3.5″	--	19.67	18.79	236°12.1′	237°01.4′	15 41.1	-19°22.9′
Neptune	♆	15	8.1	2.3″	--	31.26	30.28	262°24.3′	262°00.3′	17 27.3	-21°55.6′
Pluto	♇	15	14.0	--	--	30.55	30.09	202°08.1′	203°18.8′	13 52.9	6°26.8′

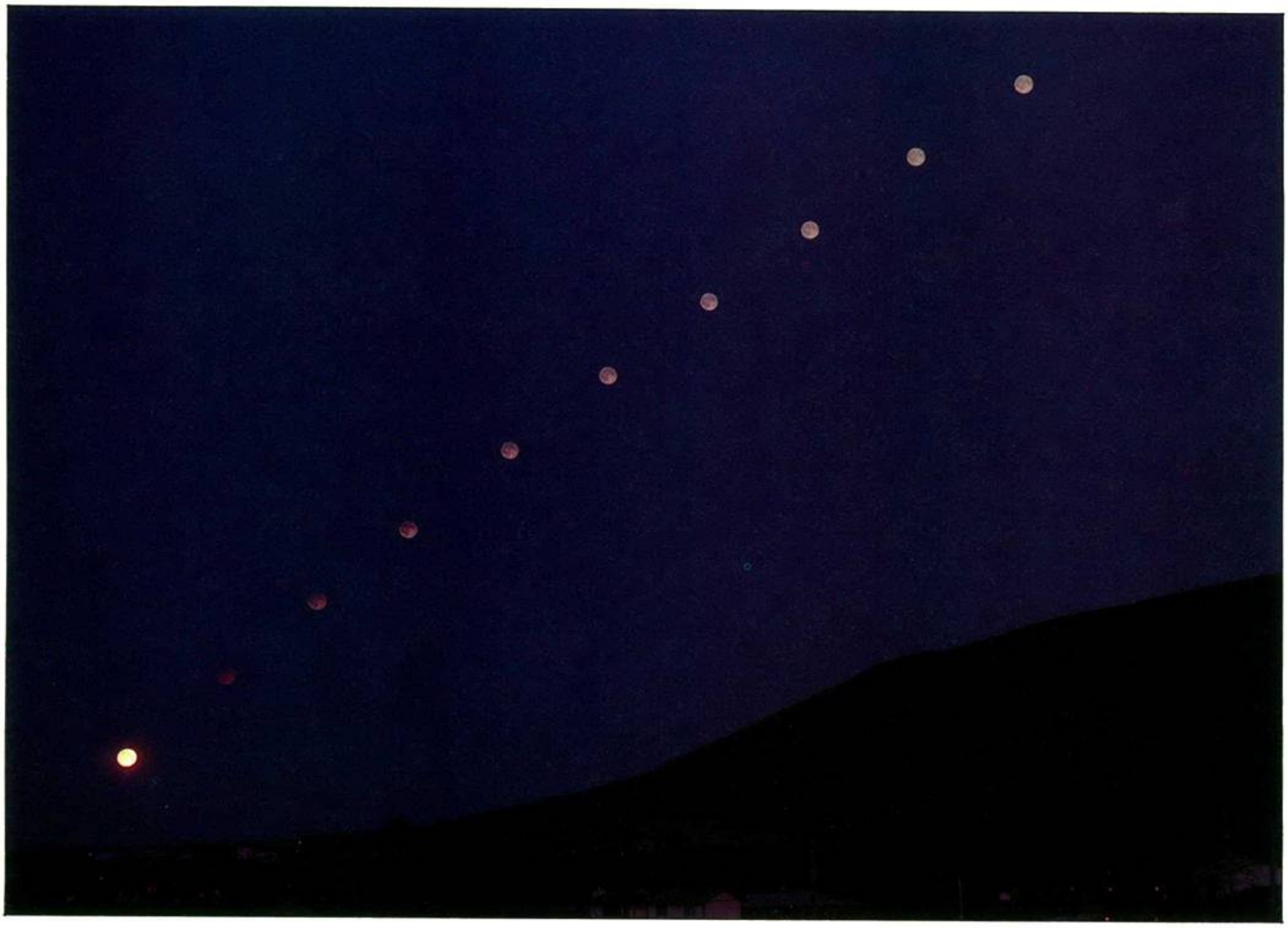
moon data

New Moon .... December 7 at 14:35
First Quarter .... December 15 at 01:47
Full Moon .... December 21 at 18:08
Last Quarter .... December 29 at 06:32
New Moon .... January 6 at 07:24

Apogee: December 3 at 4h ... 405,641 km
Perigee: December 19 at 5h... 364,340 km
Apogee: December 30 at 23h . 404,749 km

universal time

Astronomers the world over use an unambiguous system of time reckoning based on a 24 hour clock, called Universal Time (UT). Times in Through the Eyepiece are UT unless noted otherwise. To convert UT into your local standard time, subtract the following number of hours for each time zone: EST, 5; CST, 6; MST, 7; PST, 8; Alaska and Hawaii, 10. For example, if an event is to happen at 03:00 hours UT on Jan. 2, then the time in EST would be 10 p.m. Jan. 1. Likewise, 03:00 UT on March 5 becomes, in PST, 7 p.m. on March 4.

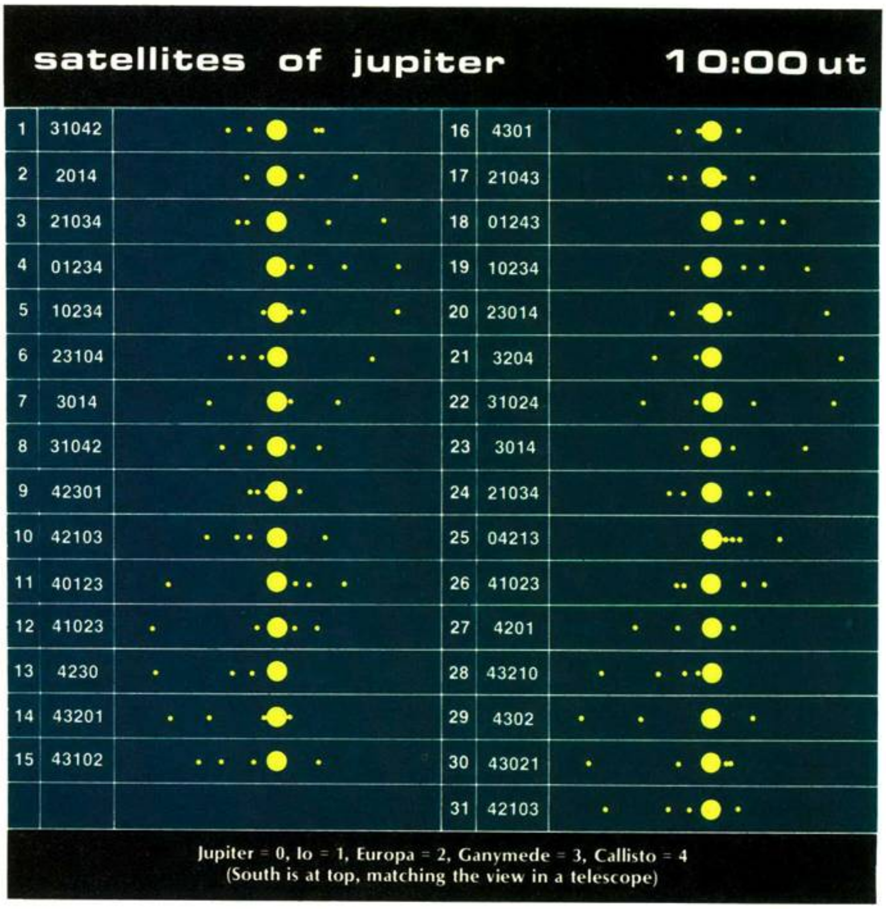


The penumbral lunar eclipse on August 25 was multiply- photographed by Dan Ostergaard. He writes that the Moon rose at mid-eclipse and, with no visual comparison, didn't *look* eclipsed. Nevertheless, he kept making exposures every 15 minutes and got the Moon's emergence from eclipse after all!

Moon often passes by bright planets and stars — and December is no exception. Here's the run-down:

On the 1st, a 35% illuminated waning crescent Moon will pass 2° north of Jupiter and 3° north of Saturn (Jupiter at 17:12 UT, Saturn at 21:25 UT). The moment of conjunction with Jupiter can be seen from both east and west coasts of North America (albeit after sunrise), but the conjunction with Saturn comes after moonset for the east coast — none of which matters much, for the view you'll get of the three, high in the pre-dawn sky on the 1st, will be very pretty from all parts of the continent.

On the mornings of the 2nd and 3rd, the Moon, growing thinner day by day, will be near Spica. By the morning of the 4th, it'll lie 5° above Venus. At the actual time of conjunction with Venus (20:45 UT), the pair will have set for viewers on the east coast, though west coast watchers can still see it. But



satellites of jupiter 10:00 ut

1	31042	16	4301
2	2014	17	21043
3	21034	18	01243
4	01234	19	10234
5	10234	20	23014
6	23104	21	3204
7	3014	22	31024
8	31042	23	3014
9	42301	24	21034
10	42103	25	04213
11	40123	26	41023
12	41023	27	4201
13	4230	28	43210
14	43201	29	4302
15	43102	30	43021
		31	42103

Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4
(South is at top, matching the view in a telescope)

the Sun will also be up then, and so the best views come before sunrise on the morning of the 4th.

Forty-five minutes before sunrise on the 5th, the Moon, now only 6% illuminated, will be 9° above Uranus; both will be low (Uranus about 6°) and relatively dim, so don't expect a prominent sight. At time of conjunction (23:46 UT) they have set for North American viewers.

Two days after passing through New, the Moon will sweep by Mars, 3.5° to the north. The conjunction (on the 9th, at 20:41 UT) comes during daylight for us, and our best views will be later that same day in the evening.

On the evening of the 19th-20th, you'll see the Moon, a day before Full, rising close to Aldebaran, the brightest star in Taurus. From the U.S. and southern Canada, the event will be only a more or less close conjunction, but observers in the far north (i.e., the Northwest Territories, Hudson's Bay, and the like) will see an occultation. The moment of closest approach comes later that night (at 8:27 UT on the 20th), when the Moon and star will be low in the west (as seen from the east coast) and high in the southwest (from the west coast).

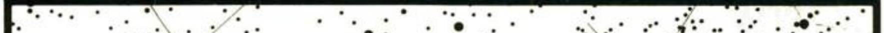
The day after Christmas, a waning gibbous Moon will pass 1° 12′ north of Regulus in Leo. Observers living in the east can see the event at the moment of conjunction (2:56 UT on the 26th), but those in the west have to wait until moonrise, which will place the Moon to the east of Regulus. By sunrise the next morning, the Moon will be high in the southwest and well past the star.

On the 29th, less than a day before Last Quarter, the Moon again passes Jupiter and Saturn. Virtually the same show will be visible from the whole continent, but moonrise for westerners comes a little after the time of the conjunctions proper (7:07 UT for Jupiter, 8:13 UT for Saturn).

Mars

Poor old Mars, still hanging in there.... Apart from its meeting with the Moon on the 9th, there isn't much to do or say about it. Mars is low in the southwestern sky at sunset and you can find it, but when you've done that, you've just about done it all! Little more than four seconds of arc in diameter during December, the Red Planet will be a tiny, featureless, orange dot in your telescope.

minima of algol



Algol is the most easily observed of the eclipsing binary stars. The chart identifies nearby stars you can use to estimate Algol's brightness. (Don't compare Algol with Rho (ρ) Persei since that star is itself variable.) Select an eclipse that will occur at least a few hours after sunset at your location, and begin observing two or three hours before mid-eclipse. Compare Algol with the nearby stars and estimate its magnitude to the nearest 0.1 magnitude. Make an estimate every 10 to 15 minutes and continue observing until two or three hours after mid-eclipse. After the eclipse, plot your data on graph paper to reveal the shape and depth of the eclipse. The times given in the table are geocentric — they have been corrected for the time light from Algol takes to cross Earth's orbit. Predictions are based on a period of 2.8673075 days.

(times of middle of primary eclipse)

Date	Time (UT)
Dec. 1	8:52:44
4	5:41:45
7	2:30:48
9	23:19:52
21	10:36:17
24	7:25:26
27	4:14:36
30	1:03:47

Asteroids

1 Ceres lies at $7^h55^m31^s$, 27° 23′ 41″, a 6.6 magnitude object near the Gemini/Cancer border on the 15th. At opposition on January 10th, Ceres can be seen almost the whole night through.

2 Pallas, an 8.1 magnitude dot near the Cetus/Fornax border, is at 1^h 54^m 28^s, -25° 32′ 18″ on the 15th. You'll find this region well up in the southeast at sundown.

Rather dim at magnitude 10.6, 3 Juno lies at $13^h40^m46^s$, -6° 14′ 31″ on the 15th. Eastern Virgo (its current location) rises around 3 a.m. local time.

4 Vesta can be found on the 15th at 10^h 45^m19^s, 12° 51′ 02″ — which places the asteroid in the middle of Leo. At this time of the year, the Leo region rises about local midnight, so plan your observations accordingly.

(All coordinates listed are for the epoch 1950.)

Jupiter and Saturn

Moving ever closer to each other (there's a grand triple conjunction in the offing, beginning early next year), Jupiter and Saturn now rise almost simultaneously. By 2 a.m. local time on December 1st, a look in the east will show at least bright Jupiter if not also substantially dimmer Saturn — and by month's end, both are rising around local midnight.

During the month both planets (Saturn especially) will approach the beautiful double star Gamma (γ) Virginis. Use your telescope for a low-power scan from Jupiter to Saturn to Gamma Virginis. Gamma has two stellar components, both yellowish and each of magnitude 3.7. The pair's separation (4 arc-seconds) is closing, having been at maximum separation (about 6 seconds of arc) in 1920.

Jupiter's distance from us decreases by almost half an astronomical unit — 69 million kilometers — and correspondingly its apparent size grows from 33.9 arc-seconds to 36.8 (equatorial diameter) over December. In the same period, its brightness will increase by a fifth of a magnitude: from -1.4 to -1.6.

By the end of the month, it will have developed a slight but distinct "out-of-symmetry" (called the defect of illumination) to its already oval disk. This comes about because in the jovian sky, Earth is at greatest eastern elongation. (To us, Jupiter has reached

In mid-September, Venus lay close to M-44, the Beehive Cluster, in Cancer. Brent Lang of Ogden, Utah, took this photo of the pair with a 135 mm lens and 2x teleconverter, 200 ASA slide film, and a 1 minute 45 second exposure at f/5.6. The camera and lens rig was piggyback-guided on his 8" Newtonian.

quadrature.) When this happens, we view Jupiter a little to one side — producing a small phase effect. Geometrically, the phase is only a third of a second of arc, but with the already somewhat darkened limb of the planet, the effect is noticeable in large instruments. (Saturn also has a phase effect right about now, but its defect of illumination comes to only a sixth that of Jupiter and usually passes undetected with all but the most careful of measurements.)

Like Jupiter, Saturn will also show an increase in size and brightness during the month, but the amounts are less. Saturn is twice as far away as Jupiter and so the changes due to our orbital motion have less effect on its observable properties. Apparent size increases from 16.7 arc-seconds to 17.7 (equatorial); brightness gains only a tenth of a magnitude, +1.1 to +1.0.

Uranus

Having emerged from the Sun's glare after conjunction, Uranus can be found low in the morning sky. At the eastern edge of Libra, it won't cross into Scorpius until late in 1981.

Neptune

Neptune, trailing a month behind Uranus, is in conjunction with the Sun on the 14th at 6^h UT and will be invisible just about all month.

Meteors

The big (and almost the only) meteor show this month is the Geminid display, scheduled to reach peak activity between 23^h UT on December 13th and 4^h UT on the 14th. Normally, the Geminids have moderate to strong numbers, so this year may be very good. The Moon's near First Quarter — and will set by midnight.

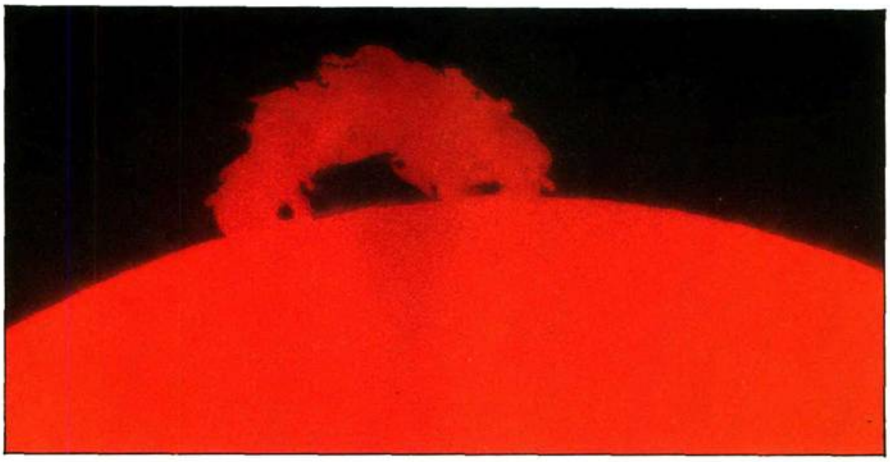
The other shower, the Ursids, comes from Ursa Minor (the Little Dipper). It has had rather sparse numbers in the last several years, but this year its "parent comet," comet Tuttle, will have returned to perihelion, and there's a good chance you'll see quite a few. Peak activity comes on December 22nd at 3^h UT, but the Moon couldn't be much worse: less than a day past Full.

close-up on camelopardalis

The circumpolar constellation Camelopardalis is large and rather dim, with no stars brighter than the fourth magnitude. Supposed to represent a giraffe (not a camel as its name seems to suggest), Camelopardalis is not an especially rich region for deep-sky explorers. Still, for those who will venture into the celestial desert of the giraffe, there are oases of interest and excitement.

Barns considered the "most inviting portion of this mammoth constellation" to be its western sector, near the boundaries with Perseus and Cassiopeia. He wrote, "In the area between declination 50 and 60 degrees will be found many dazzling gems." Indeed, a quick perusal of the Struve catalogs of double stars reveals hundreds of faint double and multiple stars scattered throughout the constellation. Unfortunately, the lack of prominent stars makes many of Camelopardalis' objects rather difficult to locate. A good star atlas in combination with our chart is essential to help track down this region's somewhat hidden treasures.

The first double star listed in our table is **1 Camelopardalis**, a pair of sixth and seventh magnitude white suns separated by 10.3 seconds of arc in position angle 308°. No definite orbital



This large solar prominence was photographed by Richard Andreassen at 15:30 UT on August 17th. He used a 14-inch telescope, an H-alpha filter, and a quarter-second exposure on 400 ASA slide film.

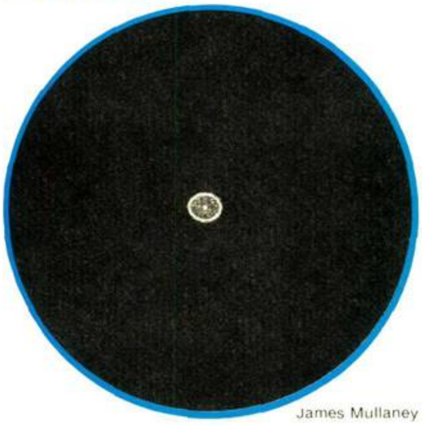
motion has been detected, so it is not known if there is a physical connection between the two.

The brightest and best stellar duo in this constellation, however, is **32 Camelopardalis**, located along a line from Mizar (in the Big Dipper's handle) to Polaris, about 7° from the Pole Star. With a combined magnitude of 4.8, 32 is easy to locate in a finder.

Also (and often better) known by the designation **Struve 1694**, 32 consists of two well-matched stars differing in brightness by only half a magnitude. Separated by an easy 22 seconds of arc, the fainter star lies near position angle 325° with respect to the brighter one. Although, as in the case of 1, there has been little sign of orbital motion to date, these two suns are moving across the sky together as a common proper motion pair, and are therefore gravitationally bound to each other. Both stars are spectral type A, so there should be little if any difference in hue — and in fact Smyth calls both bright white in cast. But others see the primary as pale yellow in tint and the companion bluish or lilac. There is an unseen spectroscopic member circling the fainter star with a period of 3.3 days.

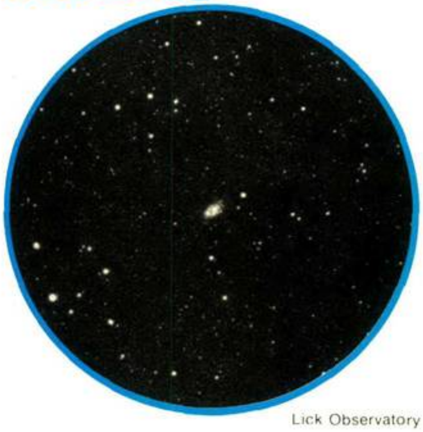
Turning to variable stars, we find two superb ruby gems in this region. Both are semiregular variables of the deep red spectral class N5. The first is **U Camelopardalis**, situated just 3° due west of the open cluster NGC-1502. Its light varies from magnitude 7.7 to 8.7 over a period of roughly 400 days. The other is **ST Camelopardalis**, about 2° north and slightly west of Alpha (α) Camelopardalis. Its range is 6.9 to 8.3 magnitude, but no certain period has yet been discovered.

NGC-1501



James Mullaney

NGC-2403



Lick Observatory

Both objects are stunning sights in small telescopes over their entire ranges, and larger apertures enhance the view even more, bringing out the ruddy tints more strongly.

A particularly strange variable is **RU Camelopardalis**, because this star, once a Cepheid variable, has apparently stopped pulsating. The only case of its kind known, RU diminished its variability gradually over the years from 1961 to 1965, and has been constant at magnitude 8.5 ever since. It is not necessarily surprising that a Cepheid star should cease pulsating, but for one to do so over a period of years rather than centuries is a definite mystery. RU's period was originally 22 days, and its amplitude nearly a whole magnitude (from 8.3 to 9.2) — try watching it over a period of weeks, and if you *do* see it vary, you will have certainly made a place for yourself in astronomical history!

Turning to planetary nebulae, the expanding shells of gas thrown off by erupting unstable stars, we find two representatives of this class in Camelopardalis. The dim **NGC-1501** is at least easy to locate, due west of Beta (β) Camelopardalis in a naked-eye trapezoid of stars. Just under a minute of arc in diameter and slightly oval, NGC-1501 may be a full magnitude brighter visually than its estimated (photographic) magnitude of 13. At least a six-inch aperture is needed for a worthwhile view, though under excellent conditions it can be glimpsed through a four-inch telescope. Larger instruments at magnifications over 100 reveal a round, sharp-edged disk. Webb notes that the Earl of Rosse saw NGC-1501 as "a bright ring," but other observers see this planetary as more uniform in surface brightness. How do you see it?

IC-3568, located just south of the double star 32 Camelopardalis described above, is only about a third the size of NGC-1501 in diameter (18"), but at magnitude 11.6 it's considerably brighter. Look for a tiny diffuse disk of light rather like a star slightly out of focus.

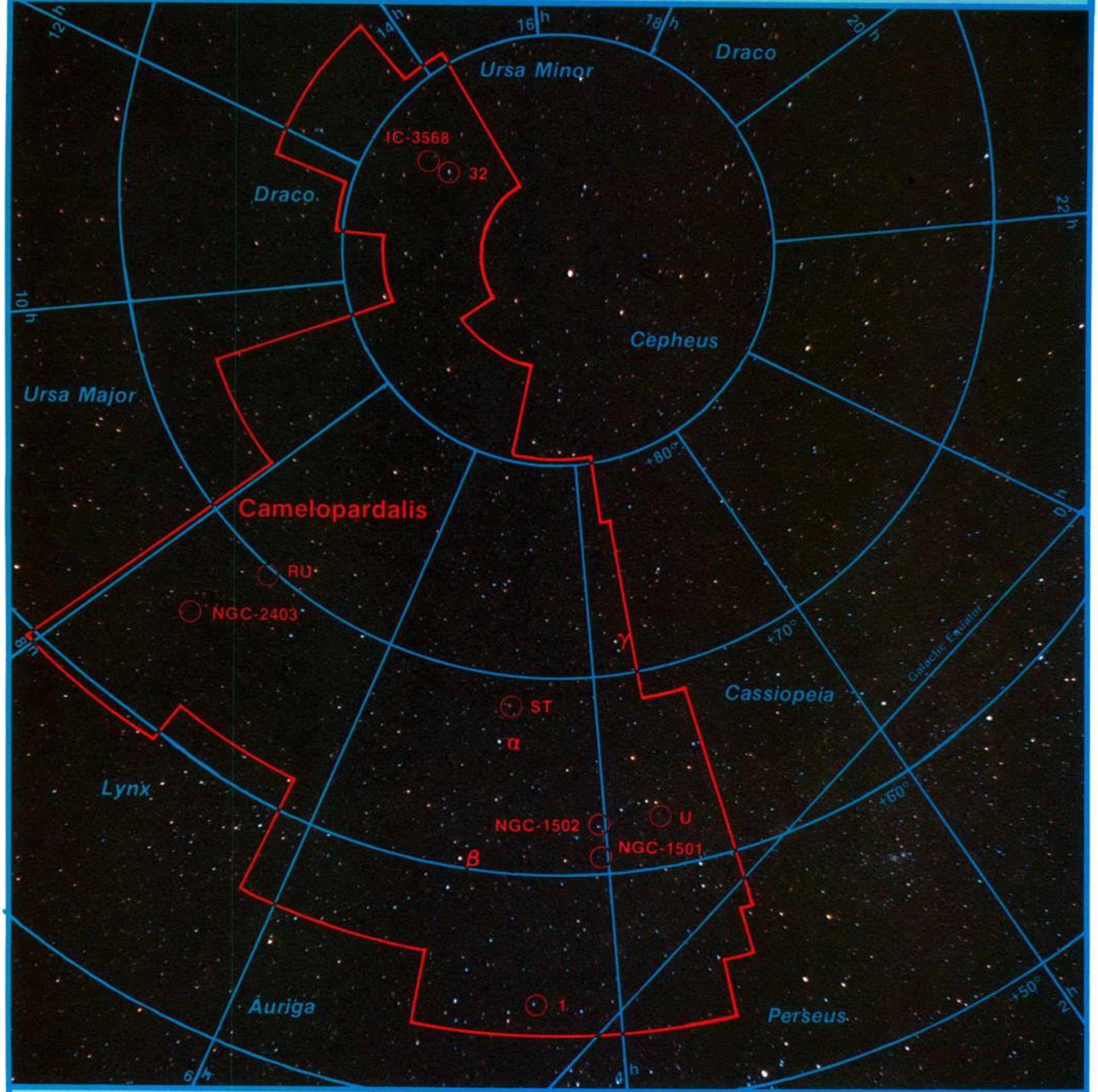
NGC-1502 is a tiny but striking open star cluster only 1½° south of the planetary NGC-1501 with its distinctive trapezoidal frame. Described by Webb as "an elegant group with seventh magnitude pair, preceded by a wider one," NGC-1502 contains about 15 stars in an area only seven minutes of arc wide. The brighter members have a triangular arrangement while the fainter ones supply a circular background to the scene. It's a fine sight in small scopes at low to medium magnifications.

Saving the best for last, we look at a striking spiral galaxy in Camelopardalis, one which surprisingly seems to have escaped the notice of the classic observers. Brighter than many of the galaxies listed by Messier, **NGC-2403** is both bright and big, shining at ninth magnitude and easily 17 by 10 minutes of arc in extent. Readily seen in three and four-inch telescopes at low power, it can even be glimpsed with a good pair of binoculars as a hazy glow. Six-inch and larger instruments provide a stunning view of a fat cigar-shaped glow floating in the void. NGC-2403 is one of the nearest galaxies beyond the confines of the Local Group, about eight million light-years distant. Break loose from the confines of the Messier list, and take a look at this neglected cosmic wonder. You won't be disappointed.

camelopardalis

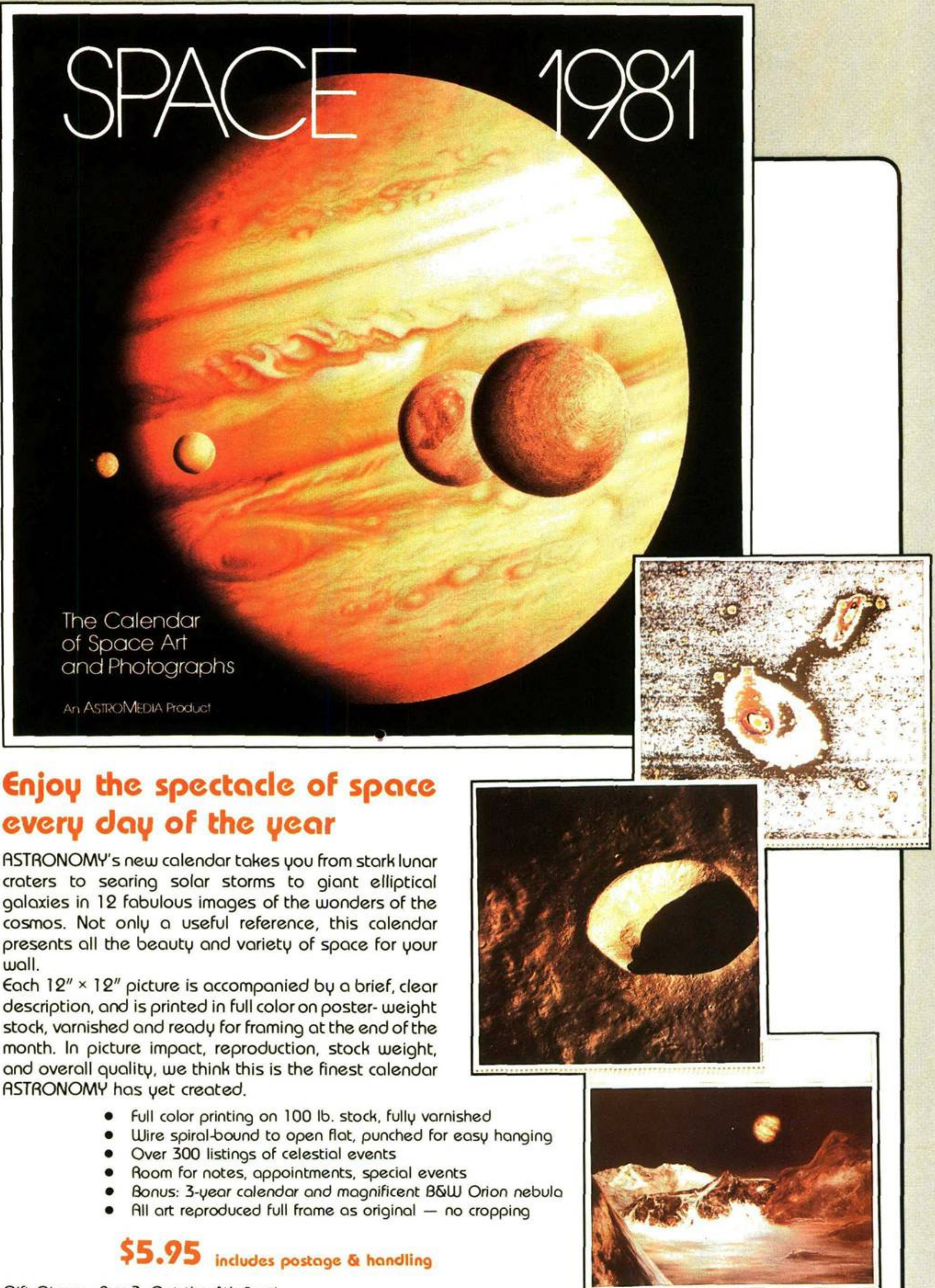
Map by Dewey Schwartzenburg

Photo by R. Provin & B. Wallis


12h
14h
16h
18h
20h
22h
0h
2h
4h
6h
8h
10h
Ursa Minor
Draco
Draco
IC-3568
32
Cepheus
Ursa Major
Camelopardalis
RU
NGC-2403
+80°
+70°
+60°
+50°
γ
Cassiopeia
Galactic Equator
ST
α
Lynx
NGC-1502
U
NGC-1501
β
Auriga
1
Perseus

Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.	R.A. (1981)	Dec.
U	m★	7.7-8.7	400 d	03 38	+62°29′	03 40	+62°35′
NGC-1501	■	13	56″x48″	04 03	+60°47′	04 05	+60°52′
NGC-1502	O	5.3	7′	04 03	+62°11′	04 06	+62°16′
1	★^{2}	5.9,6.9	10″	04 28	+53°48′	04 30	+53°52′
ST	∩★	6.9-8.3	--	04 46	+68°05′	04 49	+68°08′
RU	m★?	8.5?	?	07 16	+69°46′	07 20	+69°43′
NGC-2403	§S	8.9	17′x10′	07 32	+65°43′	07 35	+65°39′
IC-3568	■	11.6	18″	12 32	+82°51′	12 33	+82°41′
32	★^{2}	5.3,5.8	22″	12 49	+83°41′	12 49	+83°31′

★	*Star*
★^{2}	*Double Star*
★^{3}	*Triple Star*
m★	*Regular Variable*
∩★	*Irregular Variable*
Ӿ★	*Eclipsing Variable*
O	*Open Cluster*
●	*Globular Cluster*
■	*Planetary Nebula*
□	*Bright Diffuse Nebula*
§0	*Elliptical Galaxy*
§S	*Spiral Galaxy*
§ʃ	*Barred Spiral Galaxy*
§#	*Peculiar/Irregular Galaxy*



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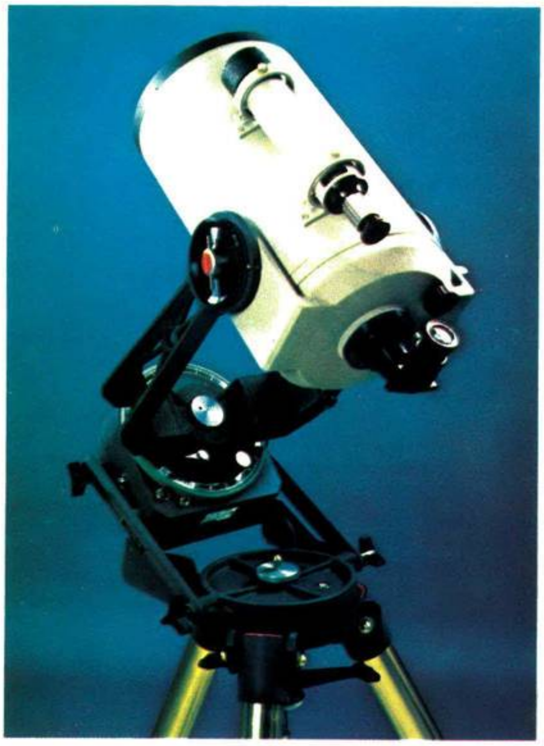
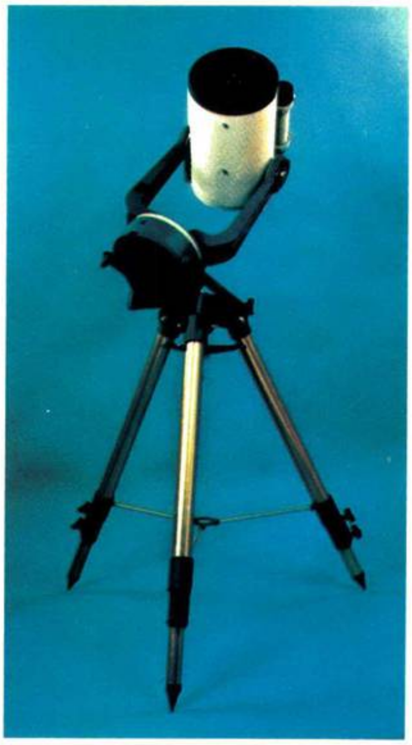


Rear view of the Dynamax 8 mounted on Dynamax Field Tripod



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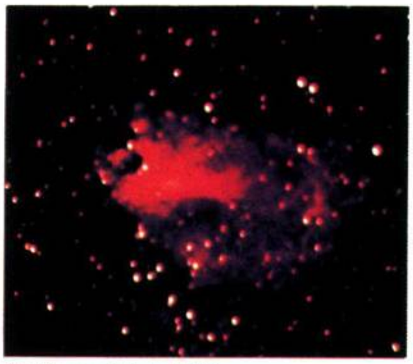

The Omega Nebula (M17) as photographed through the Dynamax 8.

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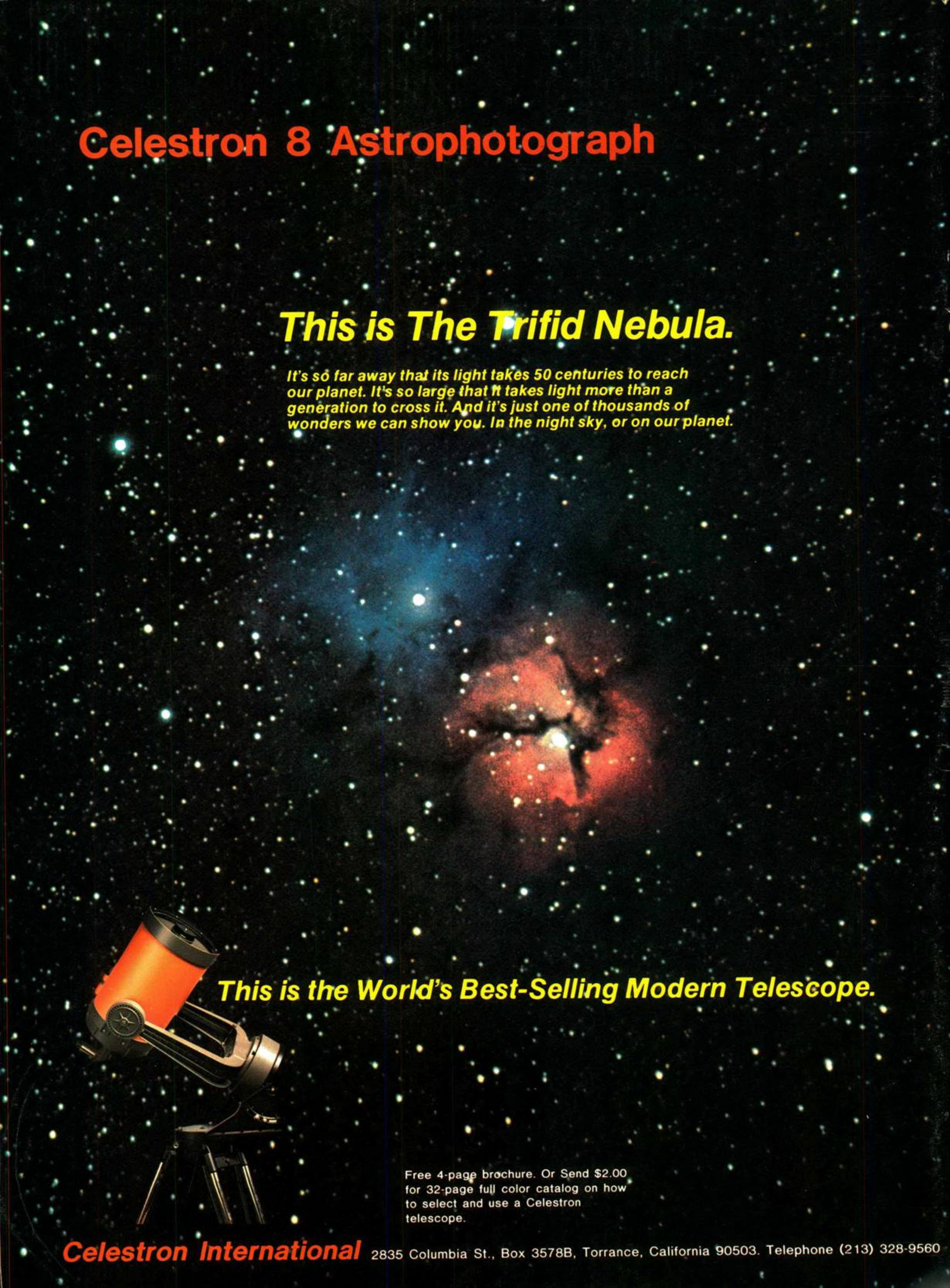

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